

# **Scientific and Operational Requirements for TOMS Data**

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## PREFACE

This document contains the proceedings of a Conference on the Scientific and Operational Requirements for Total Ozone Mapping Spectrometer (TOMS) data held at Goddard Space Flight Center, Greenbelt, Maryland on September 10-11, 1986. The conference was attended by university, industry, and government representatives who are interested in the usage and future flights of the Nimbus-7 TOMS, and assessment of the data requirements. The subjects covered included Stratospheric Processes, Tropospheric Dynamics, Remote Sensing, Volcanic Eruptions, and Future TOMS Instrument Capabilities.

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## INTRODUCTION

Total ozone has been a scientific curiosity since the 1920's when G. M. B. Dobson first observed its variations with latitude and its temporal behavior. The latitude variation led Sidney Chapman to conclude that transport was necessary to explain the equatorial ozone minimum and the temporal variation convinced Dobson that tropospheric pressure systems were modulating total ozone. The variations were so complex, however, that the network of ground total ozone stations was inadequate to resolve them even after an expansion to about 100 stations during the International Geophysical Year.

Total atmospheric ozone can be measured from space either by its absorption of sunlight in the UV Huggins bands or by its absorption and reemission of 9.6 micrometer infrared light from the surface or clouds. The UV technique was first tested on the Nimbus 4 BUUV instrument and developed to its full extent with the Nimbus 7 TOMS instrument. The IR technique was developed with data from the Nimbus 4 IRIS instrument and later implemented in the HIRS operational sounder, originally for correction of CO<sub>2</sub> band radiances for temperature sounding.

A new technique for detection of volcanic eruptions was developed with data from the TOMS instrument. Sulfur dioxide occurs in high concentrations in volcanic plumes so that they can be measured from space by virtue of absorption in narrow (1 nm) absorption bands in the 300-320 nm region.

The applications of the TOMS total ozone and sulfur dioxide data have grown tremendously over the past seven years. The original objective of the flight of TOMS was to understand the nature of the total ozone variations and their effect on ozone trend determinations from nadir viewing instruments, such as the SBUV. The reason for the present Review was to bring attention to the new applications which were not envisaged in the original program.

The research covers a broad spectrum of disciplines ranging from the Antarctic ozone hole to aviation weather to volcanic sulfur budgets. To categorize this range of topics is difficult but they were divided into five somewhat arbitrary sessions. The first session, entitled "Stratosphere" dealt with the classic ozone problems, such as photochemistry and transport between the stratosphere and troposphere.

The second session, "Troposphere," included exciting new applications of the total ozone spatial structure in diagnosis of severe storm initiation, the observation of secondary circulations in jet streams, and applications to analysis of tropical storms. A second group of topics in this session dealt with studies of tropospheric ozone variations and with the determination of UV sunburning fluxes at the surface from TOMS data. A third group of topics dealt with aviation meteorology and cabin ozone problems and with the improvement of numerical weather analysis models with TOMS data.

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The third session, "Remote Sensing," dealt with two research areas. The first considered the correlation of total ozone with tropopause height and the use of that correlation to improve retrievals of air temperature from IR and microwave sounders. The second included discussions on ground truth data and

the use of TOMS to improve the performance of Dobson stations which are the basis for ozone trend studies.

The fourth session, on "Volcanic eruptions," included talks on the detection of eruptions with TOMS, problems in validation of the data, on NOAA/FAA requirements for eruption observations, and on the uses of the data in the Smithsonian Scientific Event Alert Network.

The last session, "Future TOMS instrument capabilities" included papers on selection of wavelengths, the complementary aspects of UV and IR ozone sounding, and on proposed designs for geostationary instruments.

Finally, the current status of the Nimbus instrument and prospects for future flights were discussed.

## CONTENTS

	Page
PREFACE . . . . .	iii
INTRODUCTION . . . . .	v
OPENING STATEMENTS . . . . .	xi

### SESSION I STRATOSPHERE

Session Rapporteur: Richard S. Stolarski

Summary . . . . .	3
Richard S. Stolarski	
TOMS: The Antarctic Ozone Hole and Ozone Trends . . . . .	5
Richard S. Stolarski	
October Lower Stratospheric Antarctic Temperature and Total Ozone from 1979 to 1985 . . . . .	8
Paul A. Newman and Mark R. Schoeberl	
Systematic Stratospheric-Tropospheric Exchange Viewed from Isentropic Coordinates . . . . .	10
Donald Johnson	
Photochemical Ozone Overburden Correction . . . . .	11
Michael Stefanick and Arlin J. Krueger	
Analysis of the Breakdown of the Antarctic Circumpolar Vortex Using TOMS Ozone Data . . . . .	12
Kenneth P. Bowman	
Insights into the General Circulation of the Lower Stratosphere from TOMS . . . . .	14
Mark R. Schoeberl	

### SESSION II TROPOSPHERE

Session IIa: Dynamics

Session IIa Rapporteur: Louis W. Uccellini

Summary . . . . .	17
Louis W. Uccellini	

## CONTENTS (continued)

	Page
Ozone, Jet Streaks and Severe Weather . . . . .	20
Frank S. Sechrist, Ralph A. Petersen, Keith F. Brill, Arlin J. Krueger and Louis W. Uccellini	
Lower-Stratospheric/Upper-Tropospheric Exchange Processes Associated with Tropical Cyclones as Observed by TOMS . . .	21
Edward B. Rodgers	
Tropical Easterly Jet Located Using TOMS Data . . . . .	23
William C. Bolhofer	

### Session IIb: Other Tropospheric Applications

Session IIb Rapporteur: Arlin J. Krueger

Summary	
Arlin J. Krueger . . . . .	25
The Use of TOMS Data for Tropospheric Ozone Studies . . . .	26
Jack Fishman and Edward V. Browell	
TOMS as a Monitor of the Ultraviolet Radiation Environment: Applications to Photobiology . . . . .	27
John E. Frederick	
Northwest Airlines Flight Experiments . . . . .	31
Arlin J. Krueger	
Application of TOMS Data to Weather Analysis Models . . . .	32
Greg D. Nastrom	

### SESSION III REMOTE SENSING

Session Rapporteur: William E. Shenk

Summary . . . . .	35
William E. Shenk	
Correlations of TOMS Total Ozone Data (Nimbus-7 Satellite) with Tropopause Height . . . . .	37
Marie-Jeanne Munteanu	

## CONTENTS (continued)

	Page
An Analysis of Tropopause Pressure and Total Ozone Correlations . . . . . Siegfried D. Schubert and Marie-Jeanne Munteanu	38
TOMS Ozone Data Compared at Mesoscale Resolution to Tropopause Heights from the AVE Radiosonde Network and to VAS Radiances over the South-Central United States . . . Dennis Chesters, Louis Uccellini and David Larko	39
The Use of TOMS-Modified VAS Data for Large-Scale NWP . . . Wayman E. Baker, Marie-Jeanne Munteanu, Joel Susskind, and D. Reuter	40
Ground Truthing of NASA Satellite Ozone Measurements by Atmospheric Environment Service (AES) . . . . . Wayne J. Evans and James B. Kerr	46
Dobson-Stations Performance Assessment Using TOMS Data . . . Rumen D. Bojkov and Carl L. Mateer	47

## SESSION IV VOLCANIC ERUPTIONS

Session Rapporteur: Louis Walter

Summary . . . . . Louis Walter	51
Volcanic Eruption Detection with TOMS . . . . . Arlin J. Krueger	54
Analysis of SO <sub>2</sub> Signals in SBUV/TOMS Data . . . . . Richard McPeters	57
Comparison of Ground Based and TOMS Measurements of SO <sub>2</sub> from Volcanic Emissions . . . . . James B. Kerr and Wayne J. Evans	60
TOMS and the NOAA/FAA Volcano Support Plan . . . . . Michael Matson	70
Use of Satellite Data in Volcano Monitoring . . . . . Lindsay McClelland	71

## CONTENTS (continued)

Page

### SESSION V FUTURE TOMS INSTRUMENT CAPABILITIES

Session Rapporteur: Arlin J. Krueger

Summary . . . . .	79
Arlin J. Krueger	
Selection of Optimum Wavelengths for Ozone Mapping from Satellites . . . . .	83
P. K. Bhartia	
Determination of Total Ozone from HIRS2/MSU Sounding Data . . . . .	84
Joel Susskind	
Complementary Information Between UV and IR for Remote Sensing of Total Ozone . . . . .	85
Prabhakara Cuddapah	
Observation Guidelines for a Total Ozone Mapping Spectrometer (TOMS) in Geosynchronous Orbit . . . . .	86
William E. Shenk	
A Geostationary Imaging Spectrometer TOMS Instrument. . . .	88
Arlin J. Krueger, J. Owen Maloy, and H.B. Roeder	

APPENDIX A - Communications

APPENDIX B - TOMS Requirements Summary

APPENDIX C - NASA-X Petition

LIST OF ATTENDEES



**OPENING STATEMENTS**

**by**

**Dr. John S. Theon  
Dr. Marvin Geller  
Dr. Arlin J. Krueger**

**Dr. John S. Theon**

The Total Ozone Mapping Spectrometer (TOMS), a satellite sensor designed to measure the distribution of total ozone in the Earth's atmosphere from space, was originally intended to address atmospheric chemistry issues (the possible depletion of stratospheric ozone). While TOMS has successfully met its original objectives, atmospheric scientists have noted that total ozone patterns are highly correlated with atmospheric circulation features as well. The concentrations of total ozone are related to the locations and intensities of cyclones, anticyclones, ridges, and troughs, and strong gradients in total ozone indicate the presence of jet streams in the upper troposphere. In addition, total ozone information permits a more accurate determination of the tropopause height/temperature in satellite remote temperature soundings derived from infrared/microwave sensors.

Thus, the meteorological community has shown considerable interest in using the TOMS as a research tool in weather forecasting. A TOMS sensor, appropriately designed, could be flown in either polar orbit to observe the entire atmosphere twice daily (as has been done in the past), or in geosynchronous orbit to observe smaller scale meteorological phenomena on a more frequent basis over a limited portion of the tropics and mid-latitudes.

This Workshop has been convened to document the scientific case for continuing TOMS measurements. TOMS must compete with a number of other remote sensing proposals for a flight opportunity. I wish you success in the task that lies before you: providing the rationale for continuing the TOMS measurements.

Dr. John S. Theon  
Chief, Atmospheric Dynamics  
and Radiation Branch  
NASA Headquarters

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**Dr. Marvin Geller**

The Total Ozone Mapping Spectrometer (TOMS) was launched on the Nimbus-7 satellite in the Fall of 1978 to better understand the distribution of ozone in the atmosphere and its relation to atmospheric dynamics. It has enjoyed a varying amount of interest from NASA Headquarters and the scientific community during the intervening years. Part of this is a result of its observing a variable that is mainly associated with the stratosphere (ozone) coupled with the fact that its distribution was found to be mainly associated with atmospheric flow in the upper troposphere. Thus, neither the tropospheric or stratospheric community fully embraced TOMS at its own. TOMS data has been found to be extremely valuable in a number of areas, however, it has been of great interest in studying the Antarctic ozone hole. It has been used to study the initiation processes of mesoscale storms. It has been used to locate and characterize volcanic eruptions. It has been used to follow the geographical structure of the jet stream. It has been used to look at tropospheric chemistry, and it has been used to monitor the performance of ground-based ozone measuring devices.

It is the purpose of this meeting to bring together investigators using TOMS data in one place so that one can get an idea of the value of TOMS data across its spectrum of uses. The presently flying TOMS instrument probably has no more than a one or two year life expectancy, and it's my feeling that we will miss it when it is gone. It is very important that we accurately tell the story of the uses of TOMS data across all fields and begin planning for observations of this type that will be needed in the future. Looking at the attendance at this meeting, there is no question that you are eminently well equipped for this task. I, for one, look forward to seeing the products of this meeting and trying to work toward its recommendations.

Dr. Marvin Geller  
Chief, Laboratory for Atmospheres  
Goddard Space Flight Center

**Dr. Arlin J. Krueger**

The objectives of this meeting are several in number. A primary purpose is to review the analytical uses of TOMS data to produce a status report on the research. However, the Nimbus program is nearing its conclusion without any formal plans to continue the TOMS measurements. New flight opportunities are being discussed and we need to look at future requirements for TOMS data. Thus, the scope of this meeting includes the following elements:

1. Review past, current, and planned research.
2. Assess the need for data beyond Nimbus 7.
3. Determine whether the present TOMS design should be modified.
4. Determine which scientific requirements can be met with a polar orbiting satellite and which require a geostationary platform.
5. Create a draft set of requirements for future missions.

Because of the diversity of the research efforts, it is convenient to divide them into disciplines. A clear cut division is not possible and the names of the sessions are better taken to represent geophysical regimes rather than disciplines. For example, rather than create a separate session for the biospheric applications, they have been included in a session called "Troposphere."

The requirements for data for stratospheric applications are certainly different from those of the severe storms or volcanology areas. Thus, it may be that different platforms are required for the different disciplines.

Dr. Arlin J. Krueger  
Conference Chairman  
Planetary Atmospheres Branch  
Goddard Space Flight Center

**SESSION I**

**STRATOSPHERE**

**Session Rapporteur: Richard S. Stolarski  
NASA/Goddard Space Flight Center**

## Session I - Summary

Session Rapporteur: Richard S. Stolarski  
NASA/Goddard Space Flight Center

Summary of major conclusions concerning near future-TOMS measurement requirements for the problem of understanding seasonal and long-term features in stratospheric ozone.

- These requirements do not address the problem of mesoscale phenomena.
- Global measurements are critical. Thus, a near-polar orbit is necessary. The suggestion of putting the engineering model of TOMS on the spare NOAA spacecraft is excellent and would provide a longer baseline for total ozone trend analysis as well as instrument intercomparison.
- The global maps should be produced daily. This allows resolution of the large to middle scale waves which may be key to understanding the Antarctic ozone change. SBUV provides very useful information on the problem but does not resolve the wave structures sufficiently.
- The spatial resolution should be consistent with the temporal resolution requirement. The current mapped data product provides data on a spatial grid which is consistent with most of the major uses. The higher resolution original data have provided useful information on smaller scale processes. Thus, the present instrument has the required spatial resolution.
- Some vertical resolution would be desirable. This is a very important future consideration. If minor modification of the present instrument could be made to add one or two wavelength channels sensitive to ozone around 10 mb, this would be extremely useful.
- A critical companion measurement for TOMS at roughly the same horizontal resolution of TOMS is stratospheric temperature, especially in the region of 10-100 mb.
- Maintenance of the measurements and their calibration over a long period is necessary. With the present TOMS well beyond the limit of its lifetime, it is critical to get another into orbit as soon as possible. The opportunity to place the engineering model TOMS on a polar orbiter designed for a 3-10 year lifetime is very strongly supported.

- Data retrieval must be timely. This means in scientists' hands in a matter of weeks. It would be preferable to receive the data in essentially real time, but the questions related to maintenance of calibration for trend detection may result in a 2 week delay as the current TOMS.
- All of the above lead to strong support for Mike Comberiate's proposal for a NASA-X satellite incorporating a TOMS, an MSU, and perhaps other temperature sensors on the NOAA D spacecraft to be flown in about 2 years!!!

## TOMS: THE ANTARCTIC OZONE HOLE AND OZONE TRENDS

Richard S. Stolarski  
NASA/Goddard Space Flight Center

The TOMS instrument aboard Nimbus 7 has proved invaluable for the investigation of the recent rapid decline in the springtime total ozone over the Antarctic. We have been able to use this data to map the spatial extent of the phenomenon, discovering in the process that the decline extends beyond the polar minimum to the maximum region located at about 50 degrees south where virtually no ground-based stations are located. We have further been able to show that the minimum values of total ozone decline rapidly during September, and that this decline is accompanied by an increase in the maximum value observed. Thus, it appears that ozone is being redistributed during September via processes which appear stronger in recent years. The year-to-year decline in the integral over both the maximum and minimum may thus be due to different processes than those governing the rapid decline in September.

The principle problem which I would like to discuss is that of observing the atmosphere over long periods (decades) to determine whether or not trends and/or slow oscillations are taking place. The Antarctic ozone problem is in the process of changing our concept of the range of possible changes in the atmospheric ozone content. Because the changes were so large, as much as 40% over 7 years, and confined to a single region and season; global mapping and continued surveillance are necessary to characterize the evolving state of the atmosphere. Although a complete program to observe and identify causes for changes involves measurements of numerous parameters, I will confine this discussion to the total column content of ozone. Total ozone is an excellent summary parameter for the state of the stratosphere. It responds to temperature changes, and in the long term, is expected to respond to chemical changes. Thus, when changes take place in total ozone, such as the springtime Antarctic decrease it is a clear indication of an important problem, both because of environmental potential and scientific importance.

TOMS is actually overkill for this problem. That is, significantly more data is taken than is necessary to define the daily maps of total ozone over the globe. We have worked with the gridded data on its one degree latitude by 1.25 degree longitude grid. Tests have shown that the maps produced on a 2 degree by 4 degree grid are essentially equivalent to those produced from the entire gridded data set. We would thus be happy to trade some spatial information in favor of obtaining altitude information. Discussions seem to indicate that modification of the engineering model to measure ozone at around 10 mbar is readily doable.



Because the critical aspect of the search for changes in ozone is continuous data, reflight of a polar orbiting TOMS is important. Included in the flight should be a stratospheric temperature sensor and, if possible, a modification to obtain some ozone altitude information. A critical aspect of the problem is timeliness of the data. This has been the only drawback of the existing TOMS. We are now working with a data set which extends only through September 1983. It is expected that in the very near future the processing will be done within two weeks of real time. This is critical to the process of discovery of phenomena such as the Antarctic ozone hole. If such a system had been in place, we, rather than the British Antarctic Survey, would have discovered the Antarctic ozone hole.

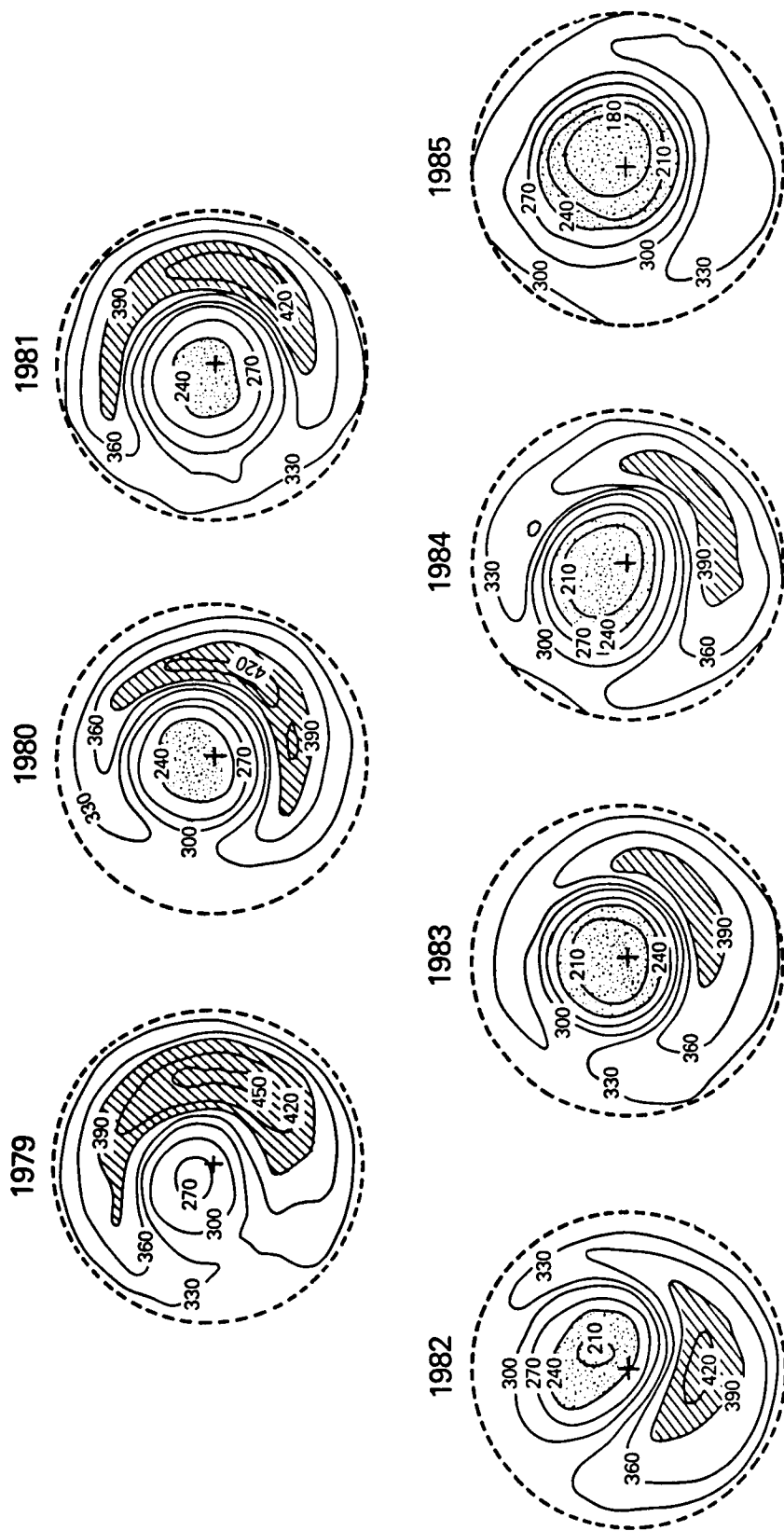


Figure 1. OCTOBER MONTHLY MEANS

OCTOBER LOWER STRATOSPHERIC ANTARCTIC TEMPERATURE AND TOTAL  
OZONE FROM 1979 TO 1985

Paul A. Newman  
Applied Research Corporation/GSFC

and

Mark R. Schoeberl  
NASA/Goddard Space Flight Center

During October, from 1979 to 1985, southern hemisphere daily plots of TOMS total ozone and lower stratospheric temperature are shown to be strongly correlated. The same result is found for the monthly averages. Additionally, these data reveal strong wave events during the ozone hole period. October zonal means of TOMS total ozone and NMC temperature are well correlated from year to year, and both are decreasing. Finally, the mid-latitude temperature maximum is found to be radically cooler in 1985 than in either 1979 (a dynamically active year) or in 1980 (a dynamically quiescent year).

### **Table 1. CONCLUSIONS**

1. Total ozone and temperature are spatially correlated.
2. Total ozone and temperature are correlated on a year-to-year basis.
4. Both total ozone and temperature are decreasing.

TOMS summary: The TOMS instrument has helped reveal the planetary scale and time variability of the ozone hole. It has revealed and confirmed various wave events, and it has enhanced our understanding of the final warming and polar vortex breakdown.

SYSTEMATIC STRATOSPHERIC-TROPOSPHERIC EXCHANGE  
VIEWED FROM ISENTROPIC COORDINATESDonald Johnson  
University of Wisconsin

Within the atmosphere's stratification, stratospheric-tropospheric exchange of mass and other properties occurs primarily through quasi-horizontal transport processes within baroclinic wave regimes and through diabatic processes either in the form of deep convection or through systematic meridional variation of incoming and outgoing radiation. These exchange processes include both extrusions of stratospheric air into the troposphere and intrusions of tropospheric air into the stratosphere. The physical processes that govern both meridional and vertical exchange processes within isentropic coordinates are summarized for the global circulation.

## PHOTOCHEMICAL OZONE OVERBURDEN CORRECTION

Michael Stefanick  
Science Systems and Applications, Inc.

and

Arlin J. Krueger  
NASA/Goddard Space Flight Center

One-half of the total ozone column is predominantly under photochemical control under all conditions except polar winter. The other half is dynamically controlled. Since the photochemical forcing is phased with the solar declination and modulated by air temperature variations in the upper stratosphere and the dynamic forcing is tied to wave activity in the upper troposphere, the total ozone column is a mixture of the two drivers. If we want to use the total ozone to infer a property of the dynamic field, namely the tropopause height, it is necessary to correct for the photochemical variations.

It should be possible to remove the photochemical component of the total ozone by using SBUV profile information along the orbital track as long as the spatial variations are low frequency. We are examining the column integral above Umkehr levels in the lower stratosphere (50 to 10 mb) to determine the level where the spatial variability decreases to the expected photochemical range to find an approximate dividing line between photochemical and dynamic control. Given this we will fit a spherical harmonic function to the ozone field and subtract this from the TOMS total ozone field. This residual field will then be correlated with tropopause height to determine whether an improvement is obtained over the total ozone correlation.

ANALYSIS OF THE BREAKDOWN OF THE ANTARCTIC CIRCUMPOLAR VORTEX  
USING TOMS OZONE DATAKenneth P. Bowman  
University of Illinois

Climatological analysis of data from the Total Ozone Mapping Spectrometer (TOMS) on the Nimbus 7 satellite has shown that the annual cycles of ozone are very different in the Arctic and Antarctic (Bowman and Krueger, 1985). The annual cycle in the Arctic is a relatively smooth annual sine wave; but in the Antarctic the circumpolar vortex breaks down rapidly during the southern hemisphere spring (September through November), producing a rapid rise in total ozone and a sawtooth-shaped annual cycle. The evolution of the Antarctic total ozone field during the vortex breakdown has been studied by computing areally-integrated ozone amounts from the TOMS data. This technique avoids substantial difficulties with using zonally-averaged ozone amounts to study the asymmetric breakdown phenomenon. Variability of total ozone is found to be large both within an individual year and between different years.

During the last decade monthly-mean total ozone values in the Antarctic during the springtime vortex breakdown period (especially October) have decreased dramatically. The ozone-area statistics indicate that the decrease has resulted in part from changes in the timing of the vortex breakdown and resultant ozone increase, which have occurred later during recent years. Analysis of the spatial scales involved in the ozone transport and mixing that occur during the vortex breakdown is now underway. Reliable calculation of diagnostic quantities like areally-integrated ozone is possible only with the high-resolution, two-dimensional, daily coverage provided by the TOMS instrument.

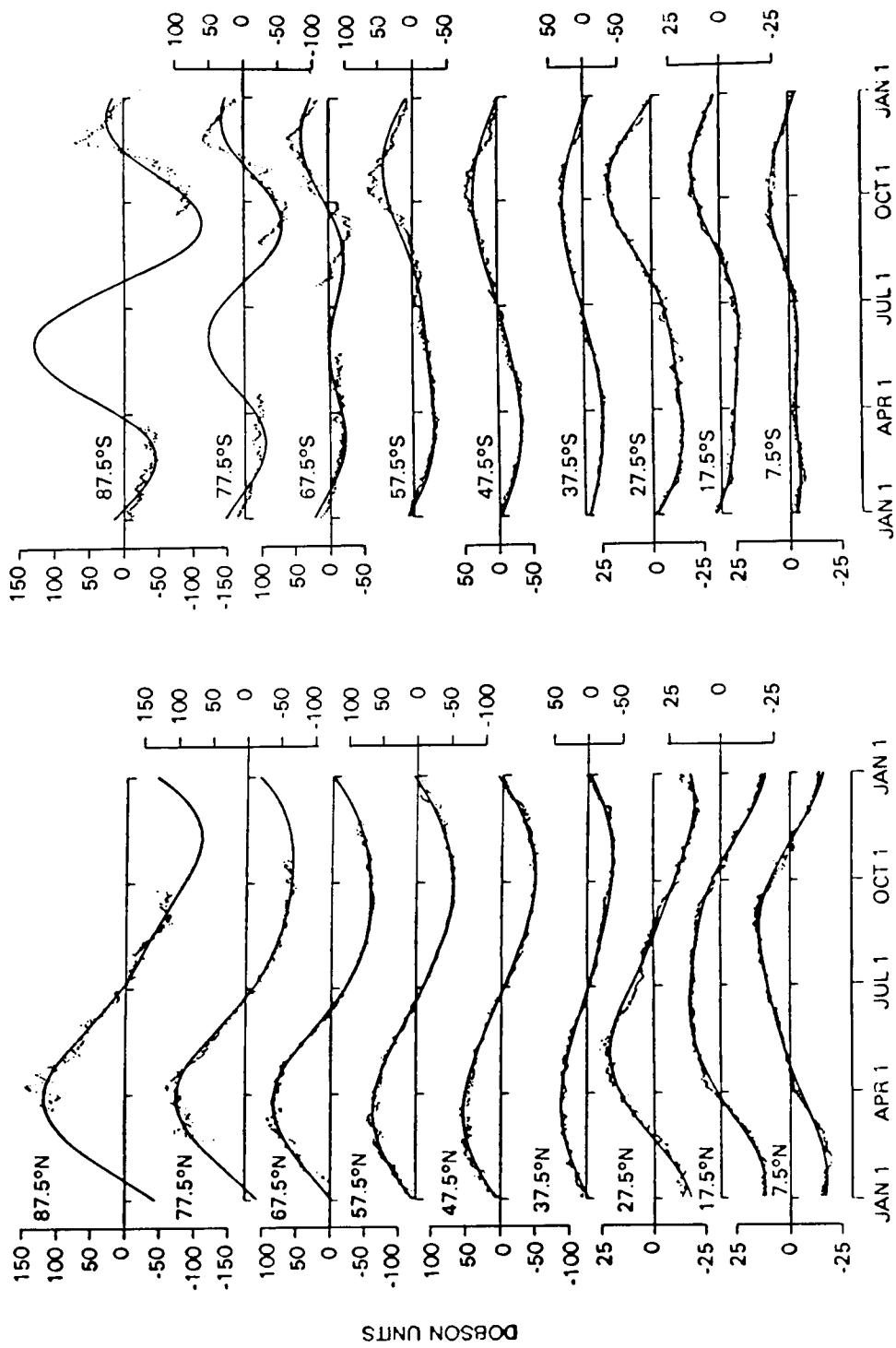


Figure 1.



INSIGHTS INTO THE GENERAL CIRCULATION OF THE LOWER  
STRATOSPHERE FROM TOMS

Mark R. Schoeberl  
NASA/Goddard Space Flight Center

Total ozone is controlled by dynamical advection as well as chemistry. At least for day-to-day variations, dynamical processes appear to be in control of total ozone. There also appears to be good evidence that seasonal and secular changes in total ozone are also dynamically controlled. For example, the zonal mean changes in total ozone in the two hemispheres in spring appear to be quite different. The TOMS total ozone data suggest a south polar spring upwelling while the Northern Hemisphere shows a clear downwelling in the same period. Radiative transfer computations support this conclusion. The secular changes in total ozone over the South Pole in spring indicate a change in dynamics rather than chemistry.

**SESSION II**

**TROPOSPHERE**

**Session IIa Rapporteur: Louis W. Uccellini**  
**NASA/Goddard Space Flight Center**

**Session IIb Rapporteur: Arlin J. Krueger**  
**NASA/Goddard Space Flight Center**

## Session IIa - Summary

### Dynamics

Session Rapporteur: Louis W. Uccellini  
NASA/Goddard Space Flight Center

The section entitled "Dynamics" consisted of four presentations: 1) "Use of TOMS Data in the Study of Cyclones" (Louis W. Uccellini, GSFC); 2) "Jet Streak Model and TOMS Data" (Frank Sechrist, Millersville State University); 3) "Upper-Tropospheric/Lower Stratospheric Exchange Processes Associated with Tropical Cyclones as Observed by TOMS" (Edward Rodgers, GSFC); and 4) "Tropical Easterly Jet" (William Bolhofer, St. Louis University). The four presentations covered a wide range of meteorological storm systems, but focused on the processes that concentrate the stratospheric-tropospheric exchange and the subsequent impact of this exchange on the storm events.

Uccellini's presentation concentrated on the use of TOMS data to confirm the presence of stratospheric extrusions before and upstream, and then during and over, rapid cyclogenetic event. Evidence was presented for several explosive oceanic cyclones in which a maximum of total ozone (as measured by TOMS) was the crucial piece of evidence to confirm the coexistence of a deep stratospheric airmass and rapid cyclogenesis. A preview of several cases was then presented from the Genesis of Atlantic Lows Experiment (GALE), which has 3-h radiosonde data, TOMS data, VAS moisture imagery, and the in situ measurement of ozone and water vapor from a Sabreliner aircraft (under the direction of Dr. Ronald Smith, Yale University). This review demonstrated that the GALE datasets should prove to be quite useful for assessing the accuracy of TOMS when depicting maximum ozone within tropopause folds upstream and during cyclogenetic events. The presentation by Uccellini ended with a review of a mesoscale numerical simulation of the Presidents' Day cyclone on February 18-19, 1979 which clearly demonstrated the narrow scale ( $10^2$  km) of the tropopause fold and the associated stratospheric extrusion. It is within these narrow zones that a large volume of stratospheric air, marked by high values of potential vorticity and ozone, descends into the troposphere. The small spatial scale plus the rapid evolution of the total ozone pattern (as demonstrated by the case of explosive Pacific cyclogenesis being analyzed by Professor Richard Reed), in rapid cyclogenesis dictates the need for mesoscale measurements of total ozone ( $10^\circ$  km spatial resolution, .5 to 1 h temporal resolution). These requirements point to the need to have the capability of measuring total ozone in geostationary orbit for both day and nighttime studies.

In the Sechrist presentation, data from three independent observing platforms were synthesized to study the role of stratospheric-tropospheric exchange processes near jet streaks

and the possible role of these processes in severe weather events. The three data types are the conventional radiosondes, 6.7  $\mu\text{m}$  water vapor imagery from VAS, and the total ozone measurements from Nimbus 7. Diagnoses were then made of potential vorticity, mid-tropospheric moisture, and total ozone at or below the level of the jet streaks. Distinct four-cell patterns in these fields were related to jet-streak-induced vertical circulation patterns both in the entrance and exit regions of the jet streaks. This study showed the striking agreement between the ozone, water vapor, and potential vorticity distributions in isolating stratospheric extrusions near jet streaks for three individual case studies. These findings were synthesized within a new ozone/jet-streak circulation model which shows that the total ozone distribution provides a unique signature in the vicinity of jet streaks and permits identification of areas most likely to experience severe weather at a later time. Relating such observations to operational forecasting was also discussed. The main finding of this presentation is the high correlation of total ozone with the maximum potential vorticity associated with tropopause folds, where the height of the tropopause is so ambiguous.

In the Rodger's presentation, total ozone measured by TOMS is associated with western Atlantic and Pacific tropical cyclones at various stages of development which were analyzed for the purpose of monitoring storm intensity and/or intensity changes. Preliminary analyses of several tropical cyclones revealed the following: 1) horizontal variation of total ozone above a mature tropical cyclone during the summer months over the subtropics were greater than 10% of the average total ozone amount; 2) the location and relative strength of the subtropical upper-tropospheric troughs can be monitored using TOMS; 3) tropical cyclone intensification appears to be related to the juxtaposition between the tropical cyclone and the TOMS-observed troughs; 4) the total ozone minimum appears to be associated with increased tropopause height above the storm central dense overcast, which is related to the storm intensity; 5) around the periphery of the central dense overcast, a minimum total ozone is usually observed; 6) maximum total ozone is observed over the eye in some very intense storms; and 7) horizontal divergence/convergence associated with the induced secondary circulation around the outflow jets corresponds to the areas of maximum total ozone gradients. The preliminary results suggest that TOMS can be used to resolve the upper-tropospheric structure in and around tropical cyclones and can provide an indication of those processes that help to intensify and maintain these storms. Again, the rapid changes usually associated with hurricane intensification suggest the need for these types of measurements from geostationary orbit on the order of .5 to 1 h temporal resolution and  $10^\circ$  km scale horizontal resolution.

The fourth presentation by Bolhofer involved a study of the tropical easterly jet (TEJ) located over India, which plays a crucial role in the onset of the monsoon season in south-central

Asia. An analysis of this jet system for June 11, 1979 revealed that the core of the TEJ is located at 115 mb near 9° N. Time analysis of the upper-level wind field over the tropical-wind-observing ship showed a lowering of both the pressure level of maximum wind and tropopause level with an acceleration of the upper-level easterlies that mark the onset of the monsoon surge. The tropopause was as much as 20 mb lower on the equatorial side of the TEJ. Streamline analyses of the maximum observed easterly winds of India do not reveal the horizontal position of this jet. Careful analysis of the total ozone measured by TOMS for June 11, 1979 showed relatively high values of ozone south of India and a relative minimum over central India. It was observed that the latitudinal position of the TEJ on June 11, 1979 at approximately 70°E coincided with the northern edge of the relatively high ozone values. Using this as a reference, the jet core was better identified over southern India as far east as the Bay and Bengal. These limited results suggest that the gradient in the ozone measurements, although small, can be used to better analyze the TEJ preceding and during monsoon surges.

The overall impression from these four presentations was that TOMS is an extremely useful observation system for better defining the position of jet streaks and subsequent jet-related processes (for example, tropopause folds) which are mesoscale in character and can have a significant impact upon the weather. Furthermore, TOMS data provides supporting evidence that stratospheric extrusions (which represent the bottom boundary conditions for stratospheric ozone budget studies) are mesoscale in character, both in space and time. Thus, to fully resolve these processes 1) dictates the need for total ozone measurements on a time scale of .5 to 1 h and a space scale of 10° km and 2) points to the need for TOMS measurements from geostationary orbit.

## OZONE, JET STREAKS AND SEVERE WEATHER

Frank S. Sechrist (Millersville University), Ralph A. Petersen (NOAA/National Weather Service), Keith F. Brill (General Sciences Corporation), Arlin J. Krueger (NASA/Goddard Space Flight Center) and Louis W. Uccellini (NASA/Goddard Space Flight Center)

Data from three independent observing platforms are synthesized to study the role of jet streaks in severe weather. The three data types are: a) conventional radiosondes, b) 6.7 micron water vapor imagery from the Geostationary Operational Environmental Satellite (GOES), and c) total ozone imagery from Nimbus 7. Diagnoses are then made of potential vorticity, mid-tropospheric moisture, and total ozone at and below the level of jet streaks.

Potential vorticity and total ozone distributions are both tracers of stratospheric air. Theoretically, both should respond to the transverse, vertical circulations expected in the vicinity of jet streaks. Both should increase due to the sinking above the left front quadrant of the streaks. Moisture, on the other hand, increases in the ascent under the left front quadrant.

This study shows striking agreement between the three parameters independently observed from three different observing platforms. Moreover, the three severe weather case studies suggest a unique distribution of ozone, potential vorticity and mid-tropospheric moisture relative to a jet streak. This, in turn, led to the creation of a new Ozone/Jet Streak Model which shows that the total ozone distribution provides a unique signature in the vicinity of jet streaks and permits identification of areas most likely to experience severe weather at a later time. The value of such observations to operational forecasting is discussed.

LOWER-STRATOSPHERIC/UPPER-TROPOSPHERIC EXCHANGE PROCESSES  
ASSOCIATED WITH TROPICAL CYCLONES AS OBSERVED BY TOMSEdward B. Rodgers  
NASA/Goddard Space Flight Center

Total ozone associated with western Atlantic and Pacific tropical cyclones at various stages of development were analyzed for the purpose of monitoring storm intensity and/or intensity changes. The analysis is based on total ozone measurements from the Nimbus 7 Total Ozone Mapping Spectrometer (TOMS).

Since ozone may be considered a passive tracer in the lower stratosphere and the ozone gradients are strongest just above the tropopause, fluctuations of total ozone are due to variations in tropopause height and/or changes in concentration within the column caused by vertical and horizontal advection. In the subtropical northern Pacific ( $\pm 30^\circ$  longitude of  $180^\circ$ ) during August and September 1981 (the time of maximum tropical cyclone occurrence), a negative correlation  $> 0.60$  was found between upper-tropospheric geopotential heights near the tropopause level and total ozone.

Preliminary analysis of several tropical cyclones revealed the following:

1. Horizontal variation of total ozone above a mature tropical cyclone during the summer months over the subtropics were  $> 10\%$  of the average total ozone amount.
2. The location and relative strength of the subtropical upper-tropospheric troughs can be monitored using TOMS.
3. Tropical cyclone intensification appears to be related to the juxtaposition between the tropical cyclone and the TOMS-observed troughs.
4. Total ozone minimum appears to be associated with increased tropopause height above the storm's central dense overcast (CDO), which is related to storm intensity.
5. Around the periphery of the CDO, a minimum in total ozone is usually observed.
6. Maximum of total ozone is observed over the eye in some very intense storms.
7. Horizontal divergence/convergence associated with the induced secondary circulation around the outflow jets corresponds to areas of minimum/maximum total ozone, respectively.

Thus, preliminary results suggest that TOMS can be used to resolve the upper-tropospheric structure in and around tropical cyclones and can provide an indication of those processes that help to intensify and maintain these storms.



## TROPICAL EASTERLY JET LOCATED USING TOMS DATA

William C. Bolhofer  
St. Louis University

The formative stages of the onset of the 1979 southwest monsoon was marked by a WNW-ESE oriented band of marine convection over the South Arabian Sea. This convection was first observed on June 10, 1979 using satellite cloud imagery. The marine convection appeared during a major acceleration of the upper troposphere easterly wind field.

A composite vertical meridional cross-section (approximately 70°E) of upper level winds for June 11, revealed the core of the Tropical Easterly Jet (TEJ) at 115 mb, 9 1/2°N. Time analysis of the upper level wind field over the Tropical Wind Observing Ship (TWOS) polygon show a lowering of both the pressure level of maximum wind and tropopause level with acceleration of the upper level easterlies. The tropopause was as much as 20 mb lower on the equatorial side of the TEJ.

Streamline analysis of the maximum observed easterly winds over India did not reveal the horizontal position of the TEJ. Careful analysis of Total Ozone Mapping Spectrometer (TOMS) data for June 11, 1979 showed relatively high values of ozone south of India. It was observed that the latitudinal position of the TEJ on June 11, at approximately 70°E coincided with the northern edge of relatively high ozone values. Using this as a reference, the TEJ core was identified as far as NE Bay of Bengal (the limits of the available TOMS data).

## Session IIb - Summary

### Other Tropospheric Applications

Session Rapporteur: Arlin J. Krueger  
NASA/Goddard Space Flight Center

The second and third parts of the tropospheric session dealt with applications of total ozone maps for environmental studies and in practical aviation problems.

The ozone in the troposphere is only 10 to 20 percent of the total ozone column. However, this amount is well above the 2% measurement precision of TOMS so that variations in the troposphere should be detectable. Normally any tropospheric variations are masked by variations of total ozone due to changes of tropopause height, at least at extratropical locations. Jack Fishman and Colleagues at Langley Research Center have identified two situations where changes in the stratosphere are small enough that local or regional sources of tropospheric ozone are visible in TOMS maps. The clearest case is biomass burning where individual fires in Brazil have been associated with local total ozone increases.

A second case is an air pollution episode in the southeast United States which occurred in late summer when the atmosphere was quiet. A 20 Dobson unit increase of ozone was found to coincide with a polluted area associated with stagnant air. The observations of these types of events are being tested with airborne DIAL measurements of tropospheric ozone.

The uv sunburning radiation is controlled by the total ozone amount but also depends on cloud cover, time of day and season. All of the necessary information is obtained with TOMS although a model is required to convert the backscattered flux to the flux transmitted to the surface. John Frederick is attempting to develop this model which is of great interest to biologists and medical researchers.

The first real time TOMS experiment was conducted to determine whether aircraft cabin ozone occurrences could be predicted from the total ozone data. Cabin ozone, measured by FAA and Northwest airlines personnel during several commercial flights in the spring of 1981, was closely related to the total ozone patterns. The near real time availability of the data also made possible studies of clear air turbulence and jet stream winds.

The last topic covered in this session addressed the problem of errors in upper air analyses due to lack of conventional meteorological data in oceanic areas or the nonuniformity of the data base. Errors in the position of upper tropospheric troughs and ridges are readily observed in total ozone maps.

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## THE USE OF TOMS DATA FOR TROPOSPHERIC OZONE STUDIES

Jack Fishman and Edward V. Browell  
NASA/Langley Research Center

Since 1984, we have been funded by NASA's Tropospheric Chemistry Program to identify potential uses of various satellite data sets to investigate tropospheric chemical processes. At the cornerstone of this research has been the archived gridded data set of TOMS total ozone measurements. In conjunction with other conventional satellite data sets available from NOAA, such as GOES and AVHRR, we have identified numerous instances whereby enhancements of total ozone in the Tropics are clearly associated with sporadic occurrences of widespread biomass burning events. The measured increase in total ozone from TOMS (10 to 20 Dobson Units) is consistent with in situ aircraft measurements taken during biomass burning episodes.

Our studies also indicate that a very strong positive correlation exists between total ozone and the distribution of carbon monoxide (CO) in the Tropics. The CO data we used were taken from the MAPS (Measurement of Air Pollution from Satellites) data set which was flown on a 1981 Space Shuttle mission. Because CO has only tropospheric sources, its strong in-phase relationship with total ozone likewise supports the hypothesis that total ozone data can be used for tropospheric ozone studies at low latitudes.

The feasibility of extracting a tropospheric ozone amount by subtracting the integrated stratospheric ozone component from the TOMS total ozone measurement is currently being explored. Using ozone profiles derived from SAGE (Stratospheric Aerosol and Gas Experiment), our preliminary findings show enhanced tropospheric ozone concentrations over Africa and the eastern Atlantic Ocean at tropical latitudes. Other preliminary studies also suggest that TOMS data may provide a means of identifying widespread air pollution episodes over the United States during the summer when the jet stream is located north of the region of interest.

One of the future studies we plan to conduct is to compare TOMS data with tropospheric ozone cross sections (distance versus altitude) obtained from UV-DIAL (Ultraviolet Differential Absorption Lidar) which was flown over the Amazon Basin in the summer of 1985. Enhancements of ozone concentrations throughout the lowest 4 km of the atmosphere were observed by the UV-DIAL in regions that had been polluted by biomass burning. Hopefully, the gradients of tropospheric ozone measured by UV-DIAL will be captured by TOMS.

## TOMS AS A MONITOR OF THE ULTRAVIOLET RADIATION ENVIRONMENT: APPLICATIONS TO PHOTOBIOLOGY

John E. Frederick  
The University of Chicago

The flux of biologically relevant ultraviolet radiation that reaches the surface of the earth varies with (1) the ozone amount, (2) surface reflectivity, and (3) cloudcover conditions. Although TOMS is generally viewed exclusively as an ozone measuring device, the instrument in fact provides information relevant to all three items listed above. A recent application of satellite-based ozone measurements has been to develop climatologies of the biologically significant UV-B radiation (wavelengths 290-320 nm) reaching the earth's surface. A growing body of research suggests that UV-B radiation tends to suppress the immune system of laboratory mice, and field studies support extrapolation of this conclusion to the immune defenses of human skin. At tropical latitudes where the surface UV-B flux is a maximum, infectious diseases are carried by flies which transmit parasites into human skin via bites. These diseases likely develop most readily in people who have experienced immune system suppression through regular exposure to the UV-B environment. The computed distribution of surface radiation combined with information on disease incidence may clarify the role of UV-B as a suppressor of the human immune system. TOMS used in conjunction with radiative transfer calculations can here provide information of great relevance to the photobiology community.

## **TOMS AS AN "ULTRAVIOLET RADIATION ENVIRONMENT MONITOR"**

### **DATA PRODUCTS (IN NEAR UV):**

- INCIDENT SOLAR IRRADIANCE
- TOTAL COLUMN OZONE
- SURFACE REFLECTIVITY (CLEAR SKIES)
- CLOUD OPTICAL THICKNESS IN UV (CLOUDY SKIES)

**Figure 1.**

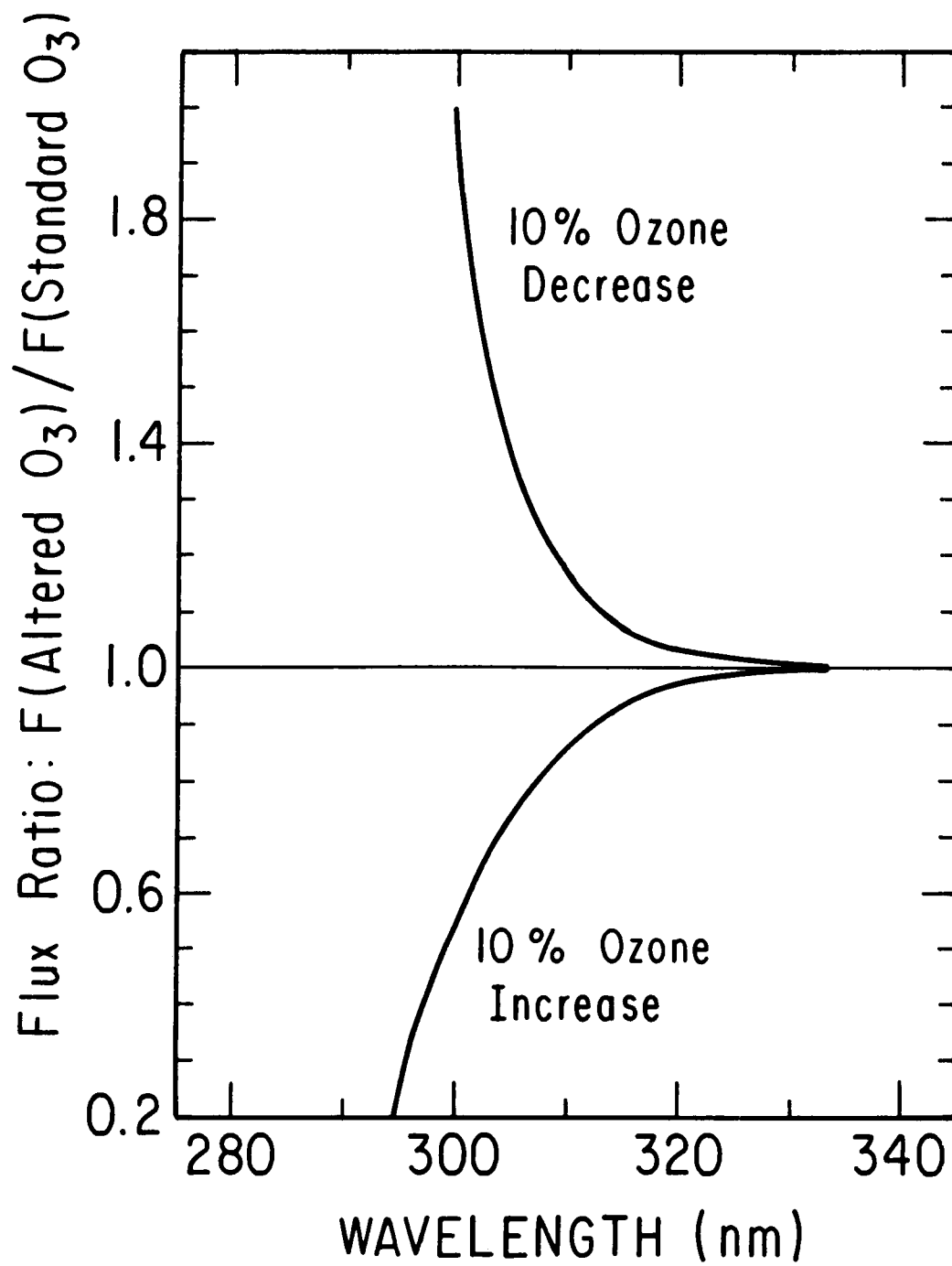


Figure 2.

# SPREAD OF INFECTIOUS TROPICAL DISEASES

U. CHICAGO - COLUMBIA U. INTERACTION

1. UV-B\* DAMAGES SKIN'S

IMMUNE SYSTEM

\* (280-320nm)



2. FLIES CARRY PROTOZOAN PARASITES & BITE PEOPLE



3. DEPENDING ON PHYSICAL CONDITION PEOPLE DEVELOP DISEASES.



Figure 3.

## NORTHWEST AIRLINES FLIGHT EXPERIMENTS

Arlin J. Krueger  
NASA/Goddard Space Flight Center

The first ozone maps from TOMS data showed spatial structures which closely resembled patterns in upper air charts. This suggested that the high resolution ozone data might serve as a proxy for these charts. However, lacking detailed, coincident temperature and wind data the association could not be demonstrated.

In March, April, and May 1981 an experiment was conducted in which realtime TOMS data was provided to the meteorological operations office of Northwest Airlines for direct comparison with their upper air charts. It was demonstrated that the regions of steep gradient in total ozone corresponded with fronts in the upper troposphere, specifically breaks in the tropopause associated with jet streams. Other small scale structure in the ozone could be related to minor trough and ridge lines. This suggested that the relation between total ozone and tropopause height might apply even on relatively small scales, and an analysis produced high correlation coefficients provided that the air mass origin was considered.

A second objective was to test the use of total ozone data for location of high cabin ozone risk areas. This was based on the hypothesis that an aircraft flying at a constant pressure level can pass from low, tropospheric ozone concentrations in a ridge (low total ozone) to high, stratospheric ozone concentrations in a trough (high total ozone). The FAA provided an instrument to monitor cabin ozone during several routine flights. The cabin ozone mixing ratio at 37,000 ft altitude was found to vary from less than 100 ppb in a ridge (300 DU total ozone) to greater than 300 ppb in a trough (400 DU total ozone).

A third analysis showed that clear air turbulence was located where upper air fronts were in rapid motion as suggested by comparison of the 1200 UT synoptic charts and the ozone map taken about 6 hours later.



## APPLICATION OF TOMS DATA TO WEATHER ANALYSIS MODELS

Greg. D. Nastrom  
Control Data

Recent studies of the errors of analysis reflected by numerical weather analysis models are reviewed. Despite the improvements in data coverage and data ingestion methods in the past decade, it is found that significant errors of analysis persist. A case study comparison of TOMS data and aircraft data with the NMC analysis over the North Atlantic is used to illustrate the size of local errors encountered. The possibility of using TOMS images to locate meteorologically significant features such as troughs and ridges near the tropopause is discussed.

**SESSION III**

**REMOTE SENSING**

**Session Rapporteur: William E. Shenk  
NASA/Goddard Space Flight Center**

### Session III - Summary

Session Rapporteur: William E. Shenk  
NASA/Goddard Space Flight Center

The remote sensing session was divided into two parts. One was mostly centered on the use of TOMS ozone measurements to estimate the height of the tropopause, and the other area focussed on the performance of measuring ozone from the ground and comparisons with TOMS data.

There were two studies presented where ozone measurements were compared with tropopause heights on a case-study basis. One of these (the paper by M.J. Munteanu) showed  $>0.9$  correlations between ozone and tropopause height over Europe for two April 1979 cases. The correlations for another 10-day period in February 1984 were 0.85 - 0.90 for the latitude band from 30-70N. Tropopause data derived from the TOMS for the two April 1979 cases were used as part of the temperature retrieval process for nearly simultaneous Microwave Sounding Unit measurements from the NOAA spacecraft. In general, MSU-derived temperature errors were reduced by 1-2K in the 400-200 mb layer for both April cases when the TOMS-derived tropopause data were included.

The other study by Chesters, Uccellini, and Larko was done using comparisons between special radiosondes taken in the midwestern U.S. within 1-2 hours of the Nimbus 7 overpass. Their correlations were lower (0.4 - 0.6) than those reported by Munteanu (0.85 - 0.95). The principal cause of the lower correlations was a several hundred km difference between the ozone maximum and the tropopause minimum. This was a case with very strong winds (65 m/sec) with the intrusion of stratospheric air well down into the troposphere. It appears that the ozone-tropopause center differences could be caused by two factors. The first is the large (~100 km) movement of the radiosonde balloons from their launch site until they reach the 300 - 200 mb level. The second is that the satellite sensor was receiving the integrated ozone from two layers in the area of the stratospheric intrusion which is where the ozone maximum was located. One layer is from above the tropopause and the second is an area of high potential vorticity in the troposphere, which in this case extended down to about 700 mb. Geosynchronous ozone monitoring should be effective in isolating those areas where the ozone-tropopause relationship is more complex.

Two studies compared tropopause heights with ozone TOMS fields where the tropopause heights were calculated from a model or determined from NMC analyses. The first study, by Schubert and Munteanu, showed lower correlations between ozone and tropopause heights in the middle latitudes than the Munteanu case studies. The relatively low resolution data ( $5^\circ \times 5^\circ$ ), the use of NMC

tropopause analyses and large time differences (up to 12 hours) could have caused at least some of the smaller correlations. However, there were still areas where the correlations were  $>0.8$ . The best correlations were over land and in the summer hemisphere. This is not surprising since (1) the radiosonde network is mostly over land and, therefore, the tropopause analysis would be better, and (2) the movement of systems is slower in the summer and the time difference effect would be reduced. The correlations were low in the tropics. This is probably the result of small tropopause variations and the difficulties with accurate tropical analyses due to large areas with little or relatively poor quality data. The second study, by Baker, et al., is studying the impact of VAS-derived temperature profiles on improving the forecast. As part of the procedure, TOMS-measured tropopause heights are included to try and improve the accuracy of the VAS temperature profiles. Baker, et al., have shown that, in the middle latitudes, there is a good correspondence between the TOMS ozone fields and tropopause heights derived from a 6-hour numerical model forecast.

There were two papers which discussed the performance of ground-based ozone measuring systems and their actual or planned comparisons with space data. Evans and Kerr reported on the performance of total ozone measurements from BREWER spectrophotometers and ozone profiles with ECC ozonesondes. An ozone profile was obtained by a BREWER on a balloon flight. They are planning to fly the BREWER instrument on the space shuttle to cross-reference the ground total ozone to SBUV and TOMS in space. Bajkov and Mateer showed extensive results of comparing Dobson station ozone measurements with the TOMS. They indicated a substantial difference in the quality of the measurements from different ground sites caused by a variety of reasons. The TOMS data are extremely useful for identifying measurement biases at individual Dobson sites. However, if the average of the Dobson measurements is compared with TOMS, then 67% of all Dobson stations are within  $\pm 2\%$  of the TOMS data and 90% are within  $\pm 4\%$ .

CORRELATIONS OF TOMS TOTAL OZONE DATA (NIMBUS-7 SATELLITE)  
WITH TROPOPAUSE HEIGHT

Marie-Jeanne Munteanu  
NASA/Goddard Space Flight Center

Two correlation studies of TOMS data with tropopause height from radiosondes performed over Europe for April 15-25, 1979, showed a correlation coefficient of 0.94 and 0.96 (different latitude bands). As a result, the rms error in the prediction of tropopause height from total ozone was found to be 20 mb.

Correlation between tropopause height and TOMS data was the highest of all the other correlations with variables directly derived from radiosondes or simulated thermal radiances over the location of radiosondes.

Comparing the two dimensional fields of TOMS, tropopause height from radiosondes and tropopause height field from TIROS-N retrievals, we can say that the first field is much closer to the true field from radiosondes than the third.

The correlation coefficient for a 10-day study, February 9-18, 1984, (related to VAS project) between TOMS data and tropopause height from radiosondes is between 0.85 and 0.9 for 30-70N.

Tropopause analysis provided by GLA model shows also a very high correlation with TOMS data. This study is performed over Europe for reasons of collocation in time between TOMS data and radiosonde reports.

## AN ANALYSIS OF TROPOPAUSE PRESSURE AND TOTAL OZONE CORRELATIONS

Siegfried D. Schubert  
University of Maryland/GSFC

and

Marie-Jeanne Munteanu  
NASA/Goddard Space Flight Center

A study of the relationship between total ozone and tropopause pressure has been carried out using 4 years of NIMBUS-7 total ozone data and NMC global analyses on a  $5^\circ$  by  $5^\circ$  grid. Maps are presented of the global distribution of variability in total ozone and tropopause pressure and their correlation for different spatial scales. The decomposition in space is done via a spherical harmonic representation where the fields are divided into large-scales (total wave number  $<6$ ) and the medium scales (total wave number  $\geq 6$ ).

The medium scales generally show correlations greater than 0.6 throughout the middle latitudes of both hemispheres with some regions exceeding 0.8. These results have been confirmed in part using station data between  $\pm 30^\circ$  longitude. The areas of highest correlations seem to be associated with the storm track regions of both the northern and southern hemispheres.

A detailed spectral analysis is performed for the medium scales on five pairs of time series (differing by latitude) of area averaged tropopause pressure and total ozone. In middle latitudes total ozone and tropopause pressure exhibit generally similar distributions in the power spectrum. In the subtropics and tropics the power in ozone drops off more rapidly with increasing frequency than the power in tropopause pressure. Only in the northern hemisphere middle latitudes does one find a clear association between increased power in ozone and tropopause pressure and maxima in the coherency spectrum.

Results for the large scales (1979 only) are more complicated showing generally positive correlations in the middle latitudes of the southern hemisphere and the middle and high latitudes of the northern hemisphere with extreme values exceeding 0.8. Some tendency for negative correlations is found in the northern subtropics particularly during the northern hemisphere fall.

TOMS OZONE DATA COMPARED AT MESOSCALE RESOLUTION  
TO TROPOPAUSE HEIGHTS FROM THE AVE RADIOSONDE NETWORK  
AND TO VAS RADIANCES OVER THE SOUTH-CENTRAL UNITED STATES

Dennis Chesters, Louis Uccellini and David Larko  
NASA/Goddard Space Flight Center

In the spring of 1982, an Atmospheric Variability Experiment (AVE) radiosonde network was operated at three hour intervals over the south-central United States, synchronized with observations from the VISSR Atmospheric Sounder (VAS) on the GOES satellite. The Total Ozone Mapping Spectrometer (TOMS) dataset from the Nimbus satellite overpass at 1700 GMT nearly coincides with the AVE/VAS observations at 1800 GMT during these experiments.

The observations on March 6, 1982 are being used to intercompare TOMS, AVE and VAS data with space-time registration errors less than 50 km and 1 hr under moderately baroclinic conditions across Texas-Oklahoma. The TOMS data shows a significant ozone maximum over northeastern Texas. The AVE radiosonde analysis shows tropopause heights with the highest pressures (lowest altitudes) over central Oklahoma accompanied by a mid-level jet across northern Mexico exiting above the Texas-Gulf Coast. The corresponding VAS radiances show a dry slot in the middle tropopause across central Texas accompanied by a secondary slot over Oklahoma. The various maxima are separated by approximately 100 to 500 km, observed with resolutions ranging from 15 to 50 km. The separations are not yet known exactly since the preliminary tropopause heights are not yet calculated objectively and corrected for balloon drift or field motion between 1700 and 1800 GMT.

Because TOMS ozone data provides information near the tropopause (a level where VAS infrared channels have very poor signal/noise and vertical resolution), TOMS is potentially useful in remote soundings. The impact of TOMS data is being assessed within a regression algorithm by comparing AVE radiosonde observations to corresponding VAS-only, TOMS-only and VAS+TOMS upper air retrievals. Preliminary results indicate no significant impact near the tropopause because TOMS ozone data is not registered (and appears statistically uncorrelated) with respect to AVE tropopause heights. After the March 6 datasets are re-analyzed and motion-corrected, the impact study will be repeated. TOMS data may require interpretation with a dynamical model before use in a mesoscale retrieval algorithm.

## THE USE OF TOMS-MODIFIED VAS DATA FOR LARGE-SCALE NWP

Wayman E. Baker, Marie-Jeanne Munteanu,  
Joel Susskind and D. Reuter  
NASA/Goddard Space Flight Center

The objectives of VAS (VISSR<sup>1</sup> Atmospheric Sounder) research in the Global Modeling and Simulation Branch are twofold: 1) to examine the usefulness of VAS data for large-scale numerical weather prediction with data collected by GOES-W from February 9-18, 1984, and 2) to attempt to improve the temperature retrieval accuracy by using independent data, such as Total Ozone Mapping Spectrometer (TOMS) data, in conjunction with VAS radiances in the retrieval program.

Collocation statistics obtained by comparing VAS temperature soundings with those from nearby rawinsondes indicate good agreement in terms of the standard deviation of the differences with values ranging from 1 K to 1.5 K (see Figure 1). These differences also compare favorably with those obtained for HIRS/MSU<sup>2</sup>. However, the VAS soundings exhibited a substantial cold bias (shown on the rhs of Figure 1) in the middle and upper troposphere, with a maximum mean difference of nearly -3 K in the region of the tropopause.

A mean difference (or "error") of this magnitude makes promising the use of TOMS in order to obtain an independent estimate of tropopause pressure for use in the retrieval program. Figure 2 illustrates a typical spatial collocation of TOMS and VAS radiances. The 1° x 1.25° gridded TOMS data (provided by Arlin Krueger), has been interpolated horizontally to the location of the VAS radiances for the TOMS data which are within ±3 h of the radiances. As may be seen in Figure 2, the 1700Z to 2300Z time period provides the best opportunity for this investigation, particularly in the northern hemisphere middle latitudes poleward of 20°. Equatorward of 20°, the horizontal gradient in the TOMS data and the tropopause pressure is too weak, as may be seen in Figure 3.

In order to improve the retrieval accuracy in the area of the tropopause, a critical issue is how well the TOMS data is correlated with tropopause pressure. This can be seen qualitatively in Figure 3. Generally, there seems to be good agreement between regions of low tropopause (high tropopause pressure values) and high values in the TOMS field. This is encouraging

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<sup>1</sup> Visible Infrared Spin-Scan Radiometer on GOES Satellites

<sup>2</sup> High Resolution Infrared Sounder/Microwave Sounding Unit



# RETRIEVAL ERROR OVER OCEAN

- VAS(~60 Retrieval-Rawinsonde Collocations)
- ▲---▲ HIRS/MSU(~140 Retrieval-Rawinsonde Collocations)
- .....■ HIRS/MSU(Clear Cases Only~20 Collocations)

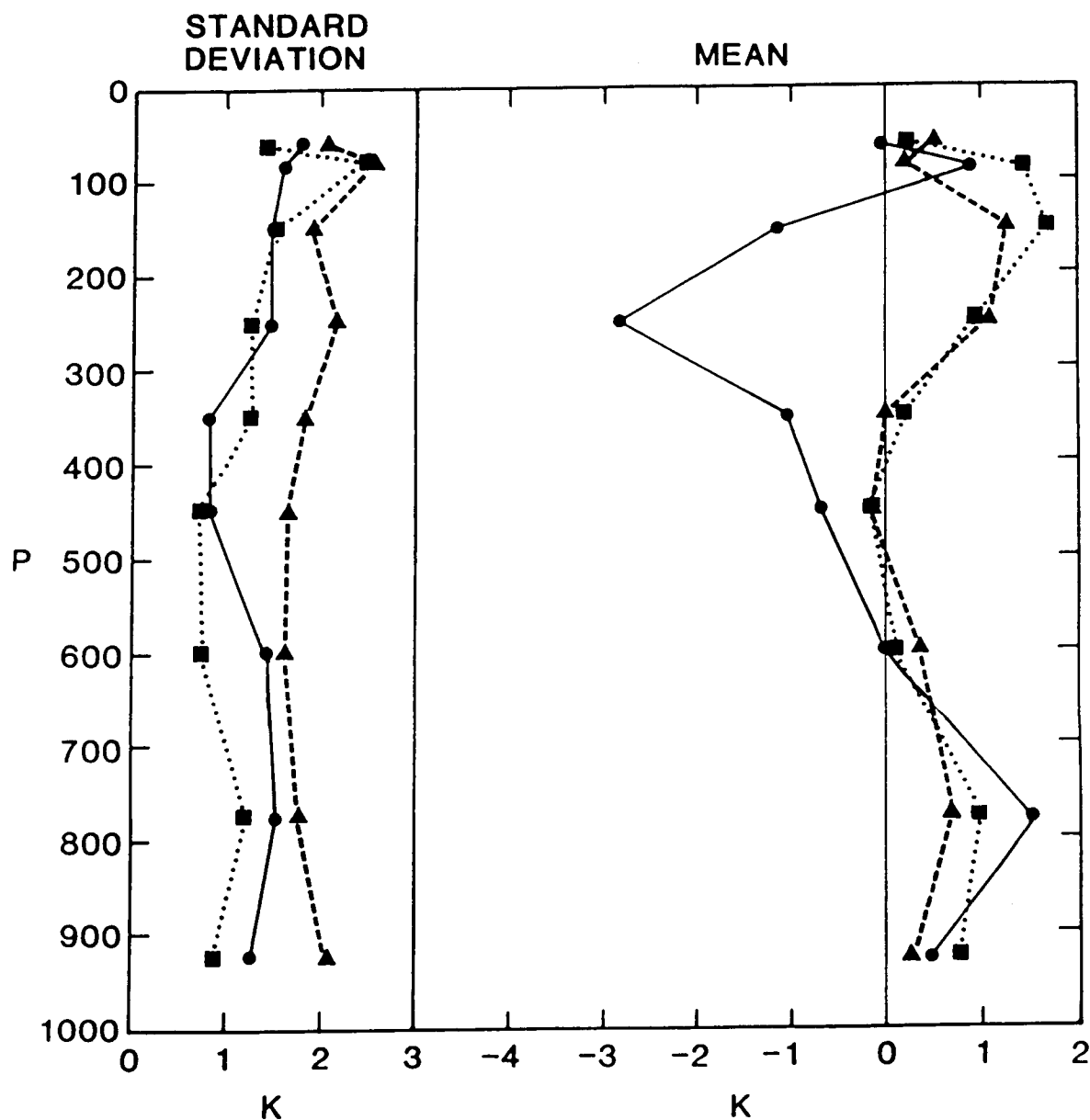


Figure 1. RETRIEVAL ERROR ESTIMATED FROM COLLOCATIONS OF VAS AND HIRS/MSU SOUNDINGS, RESPECTIVELY, WITH RAWINSONDES.

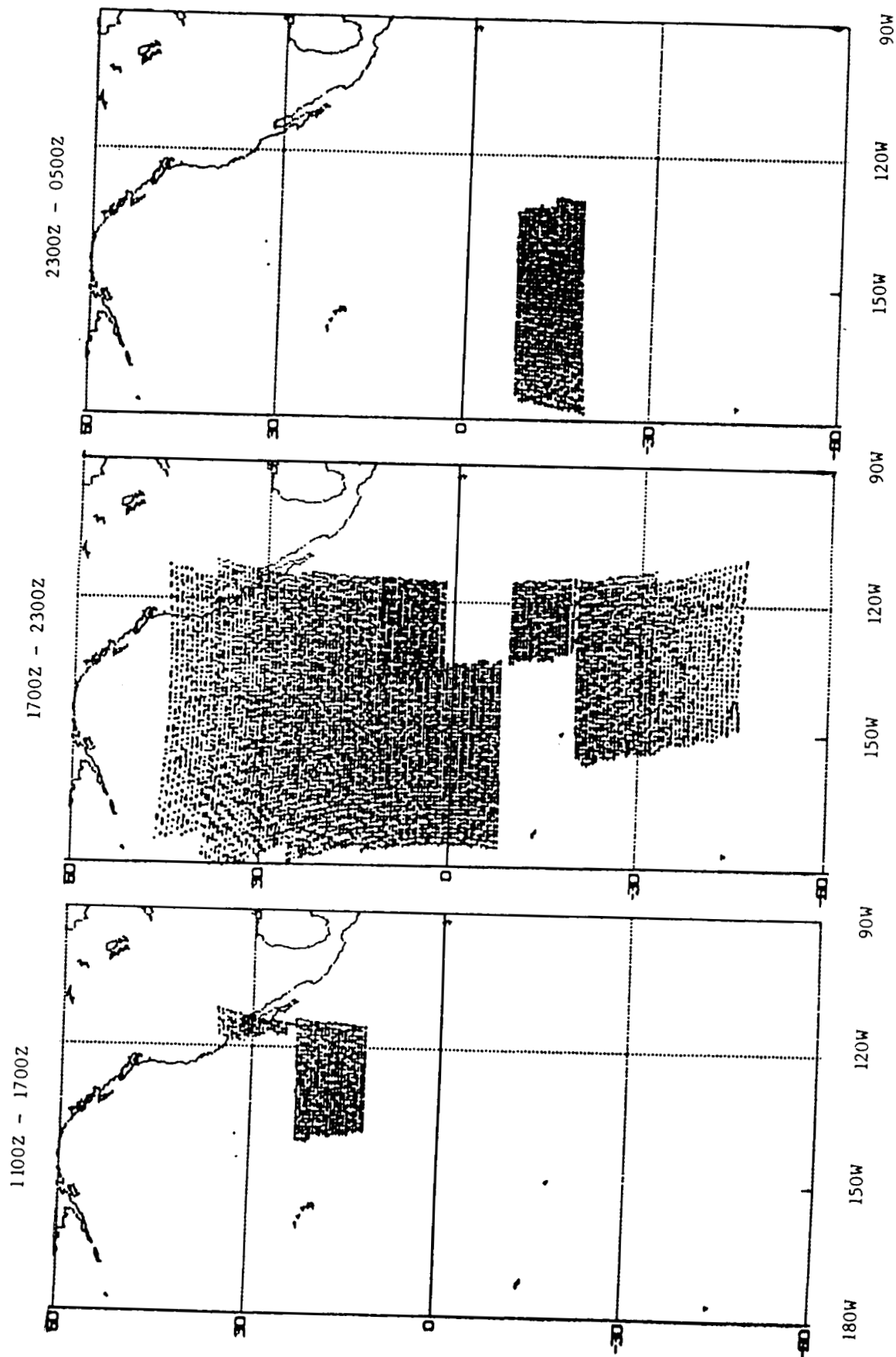


Figure 2. COLLOCATED VAS RADIANCES AND TOMS DATA FOR THREE 6 H TIME PERIODS DURING 10-11 FEBRUARY 1984.

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OF POOR QUALITY

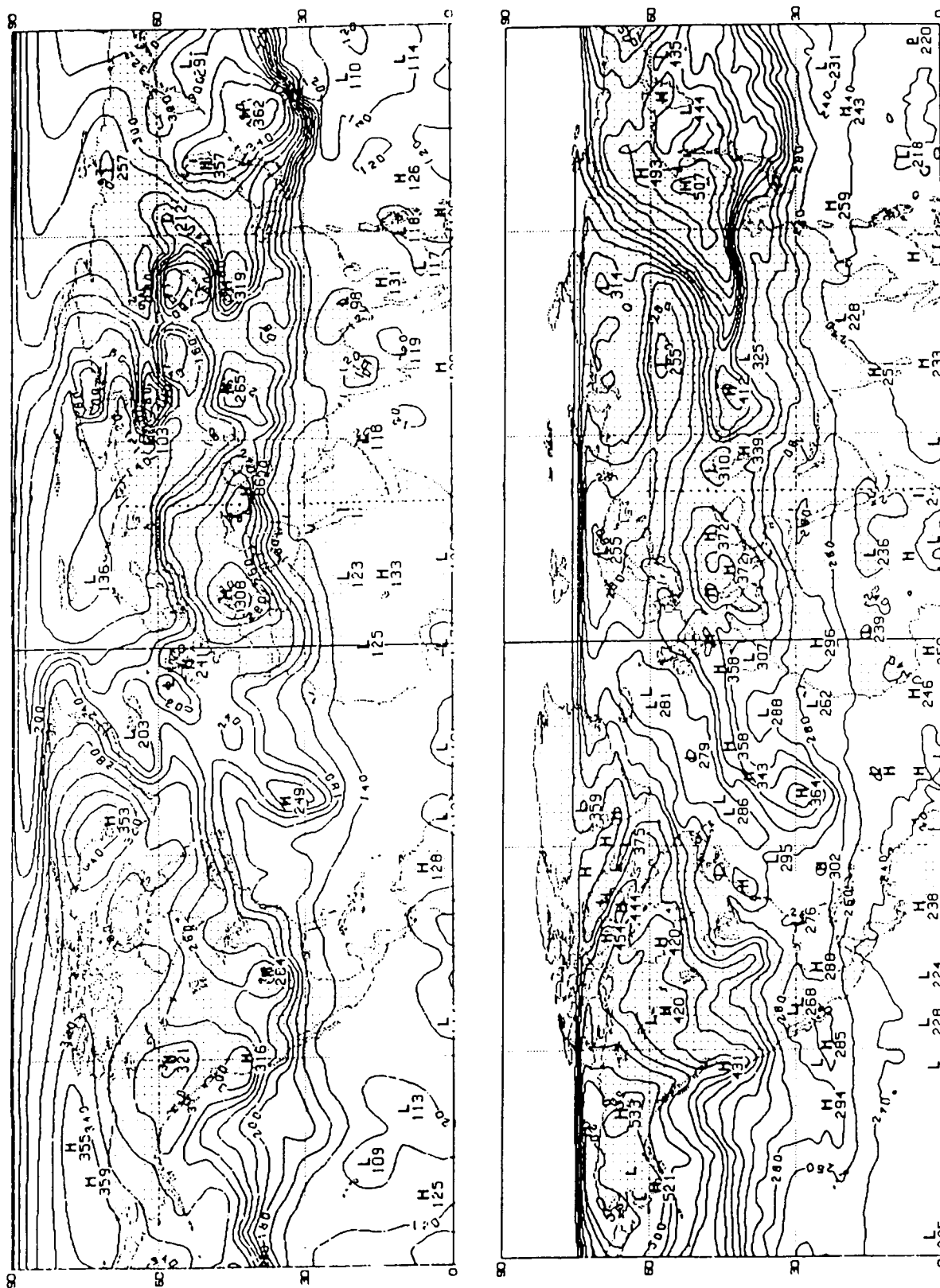


Figure 3. THE 6 H FORECAST OF TROPOPAUSE PRESSURE (in mb) FOR 1200Z 16 FEBRUARY 1984  
(Top) AND THE TOMS DATA (Bottom) AT 12 PM LOCAL TIME (IN DOBSON UNITS).

because 1) the retrievals with a low tropopause are the least accurate, and 2) regions of low tropopause are well correlated with the synoptic disturbances which represent the greatest potential for forecast improvement from the satellite data.

A quantitative assessment for the correlation of tropopause pressure, obtained from TOMS by regression and that reported by rawinsondes over Europe is shown in Figure 4. The correlation exceeds 0.8 for the 10 day period examined and is only slightly lower than the correlation between rawinsonde tropopause pressure and an analysis of tropopause pressure which used the rawinsondes.

In the future, we plan to conduct analysis/forecast experiments utilizing TOMS-modified VAS retrievals.

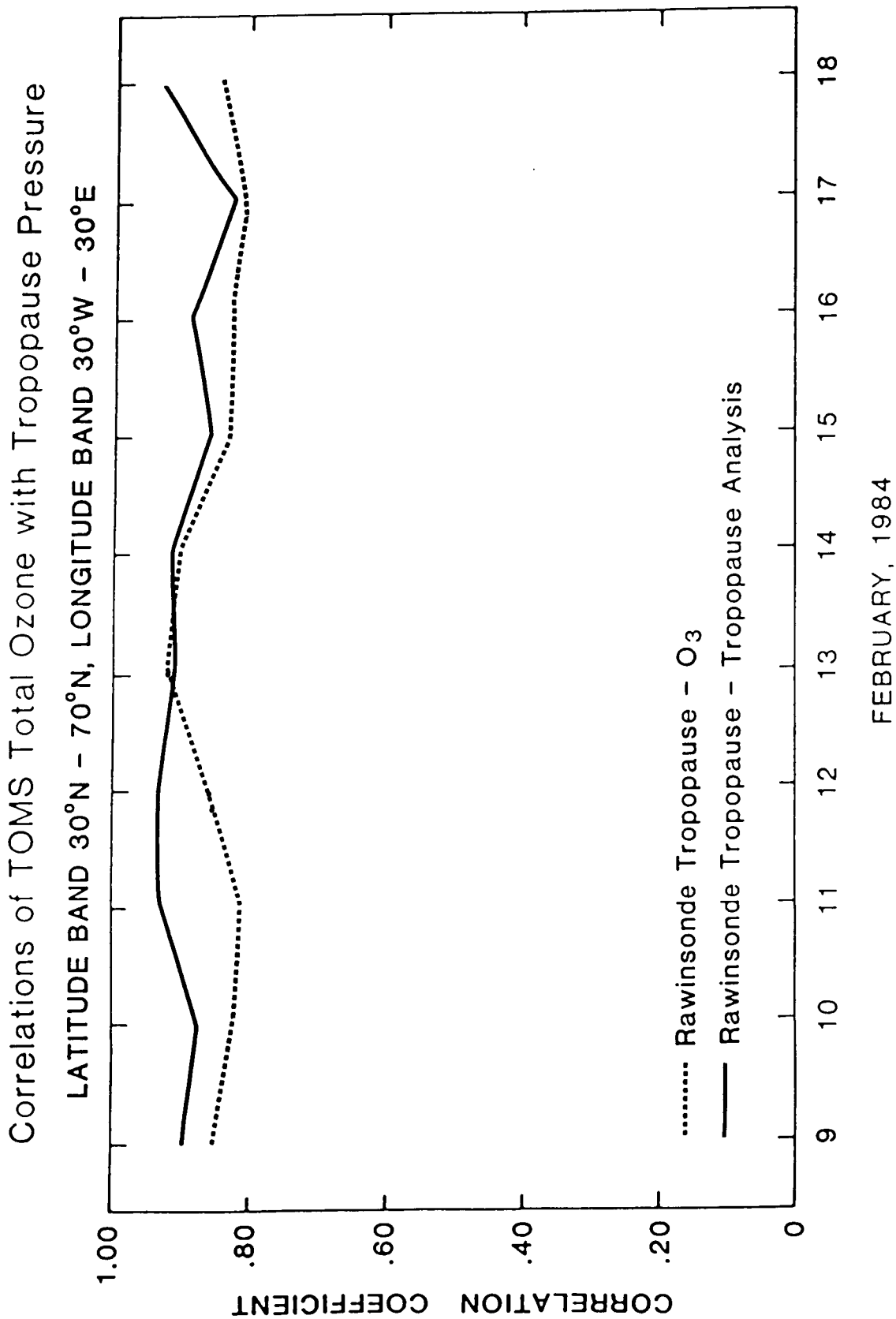


Figure 4. CORRELATION OF TROPOPAUSE PRESSURE DETERMINED FROM TOMS AND RAWINSONDE REPORTED PRESSURE.

GROUND TRUTHING OF NASA SATELLITE OZONE MEASUREMENTS BY  
ATMOSPHERIC ENVIRONMENT SERVICE (AES)

Wayne J. Evans and James B. Kerr  
Atmospheric Environment Service

AES is a world leader in the measurement and monitoring of ozone. A network of 5 stations is operated with total ozone measurements with BREWER spectrophotometers and profile measurements with ECC ozonesondes. These same measurements have been conducted on numerous field campaigns at NSBF and in Canada with one profile per day for one month. The same measurement sets were conducted during the BIC and BOIC campaigns. Data from these campaigns will be demonstrated. A BREWER was flown on a balloon flight to obtain an ozone profile in the BIC campaign. A special high altitude ozonesonde program to ground truth SBUV-2 on NOAA 9 has been conducted from Edmonton since September 1985. The results of an ozonesonde series from Alert (82.5 N) in April 1986, which was conducted to study the polar ozone profile will be discussed.

At AES, we operate the prime total ozone standard for the BREWER network with a triad of instruments. The travelling standard instrument, BREWER #17 is used to recalibrate BREWERS around the world BREWER network. As well, we have 2 BREWERS in operation which measure NO<sub>2</sub> total column and NO<sub>2</sub> profiles by the Umkehr technique.

We plan to fly the BREWER instrument into space on the shuttle to cross reference the ground total ozone standard to the SBUV/TOMS in space.

## DOBSON-STATIONS PERFORMANCE ASSESSMENT USING TOMS DATA

Rumen D. Bojkov and Carl L. Mateer  
Atmospheric Environment Service

Apart from the large natural variability of total ozone in the middle and high latitudes, the variance of available data is directly related to their quality, which is depending on the measurement techniques, the application of calibration procedures, the historical continuity of operating conditions at a given station, etc. During the past seven years, the TOMS satellite data provided a unique possibility for assessing the level of performance of ground-based ozone stations. Complete comparative assessment will stimulate common action for improving the performance of the GO<sub>3</sub>OS to meet the requirement of providing accurate and precise data for trend analysis and other studies.

Presented will be examples of comparisons of monthly summaries (based on daily measurements) at some of the regularly operating Dobson stations, with the values deduced from TOMS overpasses. Shortcomings in certain Dobson stations are identified, such as: use of an incorrect value for the extra-terrestrial constant (Hobart); sudden large value changes (Brisbane); unusually low Dobson readings (Mauna Loa); use of inaccurate cloud-blue-sky charts, causing fictitious differences with direct sun measurements (Toronto).

For the 1979-82 period, the average deviations of TOMS from the average Dobson network are:  $-6.5 \pm 1.8$ ,  $-6.3 \pm 1.9$ ,  $-5.4 \pm 2.0$  and  $-5.3 \pm 1.7$ , respectively. If this average bias is removed, the frequency distribution of the TOMS-Dobson differences reveals that 67 percent of all Dobson stations are within the  $\pm 2$  percent difference interval and less than 10 percent are outside the  $\pm 4$  percent difference. These give confidence in the quality of long-term data gathered by carefully operated Dobson stations; the Dobson stations do not provide, however, the necessary widespread geographical coverage which should rely on continuity of TOMS type of satellite operations.

In studies aiming to detect small, long-term ozone variability and trends, uncertainty of quality of measurements could cause great difficulties and lead to erroneous conclusions. Therefore, a complete study of each station should be completed and the results widely publicized. This would serve both as a warning and as guidance to potential users, who, as experience shows, are frequently taking the numbers at face value.

Continuous operation of TOMS would provide the means for assessment and guarantee the availability of global coverage of reliable ozone data.

**SESSION IV**

**VOLCANIC ERUPTIONS**

**Session Rapporteur: Louis Walter  
NASA/Goddard Space Flight Center**

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## Session IV - Summary

Session Rapporteur: Louis Walter  
NASA/Goddard Space Flight Center

Though designed primarily for measuring ozone concentrations, it has been demonstrated that the TOMS instrument can detect and assess the quantities of  $\text{SO}_2$  in the atmosphere when they are substantially above normal background. Furthermore, the relative intensities of the responses in the TOMS spectral bands permits  $\text{SO}_2$  to be uniquely distinguished from ozone. Observing at nadir, the TOMS IFOV is 50 km and it can detect as little as 200 tons of  $\text{SO}_2$ ; while off nadir, the IFOV is 150 km and 1500 tons is the limit of detectability.

This capability has permitted the detection of numerous volcanic eruptions beginning with that of El Chichon which, based on TOMS data, ejected  $5 \times 10^6$  tons of  $\text{SO}_2$  into the stratosphere. The sulfur dioxide cloud was tracked as it circled westward around the globe. On the other hand, the cloud from the Alaid (Kamchatka) eruption of 1981 traveled first northeasterly and then southward.

The SBUV nadir-viewing instrument, with a ground spot size of 200 X 200 km has a high signal-to-noise capability. It can detect as little as one milliatmosphere-cm (or 1000 tons) of  $\text{SO}_2$ . Spectral scans (in the range of 200 - 400 nm) taken by SBUV after the El Chichon eruption have shown the  $\text{SO}_2$  peaks to degenerate to  $\text{H}_2\text{SO}_4$  but such spectral data are available only once a month.

Ground-based measurements have been made of volcanic clouds at the same time that they were being observed by TOMS. Observations of the  $\text{SO}_2$  in the cloud from the Mount St. Helens eruption made on the ground in Toronto agree with those made by TOMS. However, ground-based measurements of this gas from the 1984 Krafla eruptions show about 50 times the  $\text{SO}_2$  determined by TOMS; perhaps due to low-level tropospheric gas undetectable by TOMS.

Violent eruptions may be hazardous, not only to those on the ground but also to aircraft which, several times each year and generally at night, encounter ash clouds. Usually the results are pitted windshields but, in 1982, two catastrophes were narrowly averted after ash from the Galunggung eruption clogged the turbines of two airliners. Indeed, remote areas in the Pacific where such eruptions take place are on the flight paths of many scheduled airline routes.

For this reason, NOAA is considering a plan to provide eruption alerts for the FAA. Such alerts would be based on satellite observations of ash clouds using AVHRR data and of  $\text{SO}_2$

using TOMS data. While ash clouds, even those in the troposphere, can be detected in the visible/infrared imagery of AVHRR, it is extremely difficult to distinguish them from normal clouds. Hence the importance of the TOMS data. On the other hand, TOMS would not be able to make nighttime observations.

Data on the occurrence of eruptions and the distribution of the clouds are of great interest to the scientific community, especially geologists and volcanologists. For this reason, these events are reported to those communities as quickly as possible by the Scientific Event Alert Network (SEAN) of the Smithsonian Institution. For various reasons, it is important to make ground observations at the earliest stages of an eruption so SEAN uses news and other ground-based networks and would like to have a reliable source of satellite data on which to base its alerts.

In a broader sense a continued source of TOMS data would permit global geological studies which have not been possible until now.

Because of the distribution of the world's population, many eruptions may be going unnoticed. These may be in remote areas or may occur beneath the sea. TOMS data would permit a more comprehensive knowledge of the geographic and temporal distribution of volcanos and their eruptions.

It is true, as noticed above, that the amount of  $\text{SO}_2$  emitted varies from volcano to volcano and cannot be predicted on the basis of current knowledge. Furthermore, the amount emitted cannot be easily measured using ground-based instruments. TOMS data would be instrumental in studying the relationship of the amount and rate of emission with magma/lava type and geological/tectonic setting.

In turn, this data would be extremely valuable in modeling the geochemical cycle of sulfur contribution to the solution to questions such as:

What is the rate at which sulfur comes to the Earth's surface from the mantle?

Is this rate compatible with the rate at which sulfur is buried in subduction zones?

Is there uniformity in the distribution of sulfur deep inside the Earth?

What is the rate of sedimentation of sulfur in the oceans?

There is substantial evidence that in historical times, volcanic eruptions have affected regional, if not global, climate on the annual time scale. It seems likely, moreover, that the substance which causes this is SO<sub>2</sub> which, as demonstrated, can be detected as it migrates around the Earth. TOMS data, therefore, are essential in studying the relationship between volcanic eruptions and climate.

Geological uses of TOMS data thus fall into three categories: detection of eruptions; investigation of geochemical cycles and studies of the climatic impact of vulcanism. Each imposes its separate requirements as follows:

Detection of eruptions:

Requires high temporal resolution (hourly), relatively high spatial resolution ( $\sim 10^1$  km); moderate radiometric resolution (i.e., limits of SO<sub>2</sub> detectability) and rapid data processing and interpretation.

Geochemical cycles:

Requires moderate temporal resolution (daily); moderate spatial resolution ( $\sim 10^2$  km); high radiometric resolution and ordinary data processing scheduling.

Climatic effects:

Requires moderate temporal resolution (every few days); moderate spatial resolution ( $\sim 10^2$  km); moderate-to-high radiometric resolution and ordinary data processing scheduling.

In view of these varied requirements, it may be observed that, whatever the configuration of any future TOMS instrument, it would be useful for some sort of geological studies - provided that spectral bands are chosen to permit detection of SO<sub>2</sub>.

## VOLCANIC ERUPTION DETECTION WITH TOMS

Arlin J. Krueger  
NASA/Goddard Space Flight Center

The Nimbus 7 Total Ozone Mapping Spectrometer (TOMS) is designed for mapping of the atmospheric ozone distribution although absorption by sulfur dioxide at the same ultraviolet spectral wavelengths makes it possible to observe and resolve the size of volcanic clouds. The sulfur dioxide absorption is discriminated from ozone and water clouds in the data processing by their spectral signatures. Thus, the sulfur dioxide can serve as a tracer which appears in volcanic eruption clouds but is not present in other clouds.

The TOMS instrument has been able to detect many eruptions, such as those of El Chichon and Galunggung in 1982, Una Una, Indonesia in 1983, Mauna Loa, Hawaii in 1984 and Ruiz in 1986. Other eruptions, which are difficult of detect in the visible and infrared, have been found with TOMS. An example of this is the eruption of Fernandina in the Galapagos Islands on April 1, 1984 which was only detected by its sulfur dioxide content. The detection limit with TOMS is close to the theoretical limit due to telemetry signal quantization of 1000 metric tons (5-sigma threshold) within the instrument field of view (50 x 50 km near the nadir).

This satellite-based remote sensing capability is important to aerospace operations because of a unique ability to detect and discriminate eruption clouds from weather clouds, and to quantify the sizes of the eruptions. The TOMS technique is passive and, similar to the visible light channels on the NOAA AVHRR instrument, requires sunlight for its operation. The present system on a polar orbiting satellite observes the entire earth from a sun-synchronous, local noon orbit. This provides an excellent means for surveying the earth with a single instrument. However, this limits the observations to the single time of the overpass and, therefore, to the size and location of the cloud at this instant of time. This capability is satisfactory for a survey of global volcanic activity and for verification of eruption reports. To detect eruptions as they occur, and to track the plume as it drifts with the winds, as required for an aviation hazard warning system, it is necessary to place the instruments on geostationary satellites.

**Table 1. ERUPTIONS DETECTED WITH TOMS**

<u>VOLCANO</u>	<u>ERUPTION DATE</u>	<u>CLOUD TRACK</u>
SIERRA NEGRA	13 NOVEMBER, 1979	3 DAYS
ST. HELENS	19 MAY, 1980	4+ DAYS
ALAI	27 APRIL, 1981	22 DAYS
AMBRYM	8 MAY, 1981	2 DAYS
PAGAN	15 MAY, 1981	2 DAYS
"MYSTERY"	26 DECEMBER, 1981	12+ DAYS
EL CHICHON	29 MARCH, 1982	64+ DAYS
GALUNGGUNG	5 APRIL, 1982	1 DAY
	25 JUNE, 1982	1 DAY
	14 JULY, 1982	2 DAYS
SOPUTAN	27 AUGUST, 1982	1 DAY
COLO., UNAUNA	24 JULY, 1983	1 DAY
MAUNA LOA	25 MARCH, 1984	1 DAY
FERNANDINA	31 MARCH, 1984	11 DAYS
SOPUTAN	25 MAY, 1984	2 DAYS
KRAFLA	5 SEPTEMBER, 1984	3 DAYS
	10 SEPTEMBER, 1984	1 DAY
	18 SEPTEMBER, 1984	1 DAY
RUIZ	12 SEPTEMBER, 1985	1 DAY
	13 NOVEMBER, 1985	7 DAYS
AUGUSTINE	27 MARCH, 1986	
	31 MARCH, 1986	

# MAUNA LOA ERUPTION CLOUD SEQUENCE

MARCH 25 -- APRIL 5, 1984

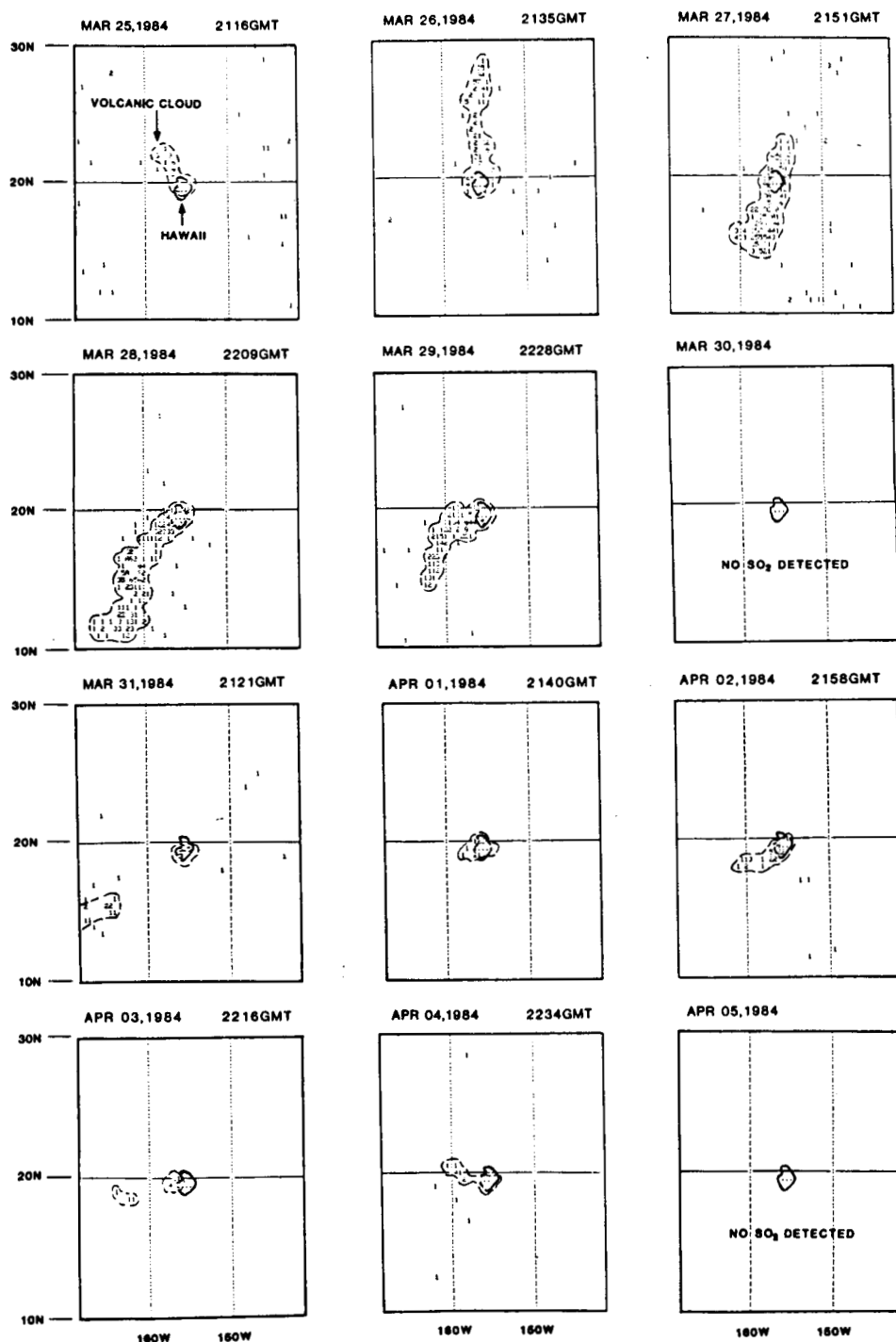


Figure 1.

ANALYSIS OF SO<sub>2</sub> SIGNALS IN SBUV/TOMS DATA

Richard McPeters  
NASA/Goddard Space Flight Center

Absorption bands between 300 nm and 315 nm were observed in spectral scans of the atmospheric albedo made by SBUV following the eruption of El Chichon. We show that these bands coincide with peaks in the absorption coefficient spectrum of SO<sub>2</sub> and use the magnitude of the absorption to estimate the column content of SO<sub>2</sub> present. These observations confirm that the differential absorption between 312.5 nm and 317.5 nm in TOMS data can be used to measure SO<sub>2</sub> with high spatial resolution. A maximum concentration of SO<sub>2</sub> of 15 matm-cm was observed by SBUV on April 15, 1982. The measurement based on direct measurement of band intensity can be used to calibrate the TOMS algorithm for deriving SO<sub>2</sub> amounts.

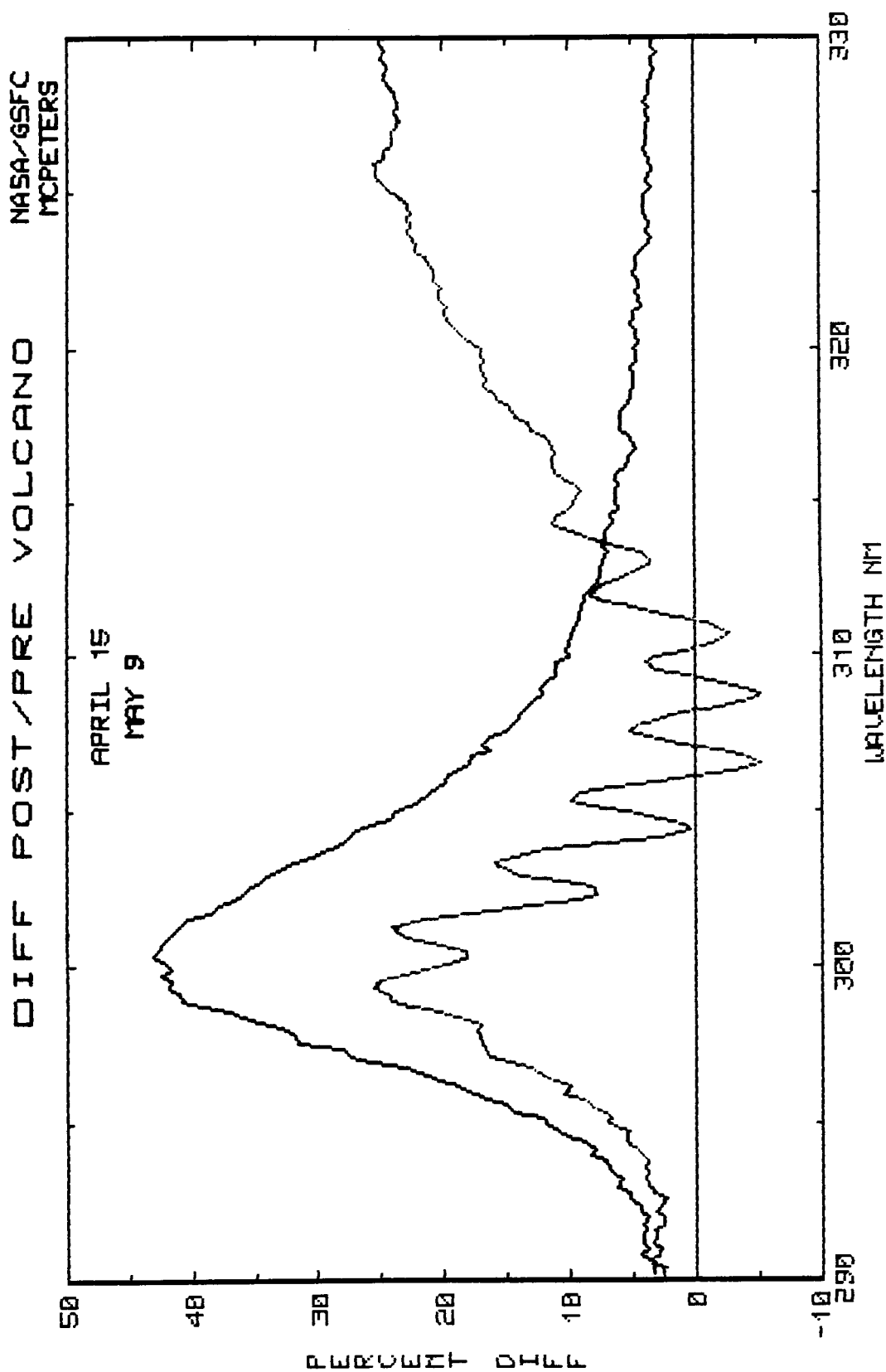


Figure 1. THE PERCENT DIFFERENCE BETWEEN THE MEASURED ALBEDO BEFORE AND AFTER THE ERUPTION OF EL CHICHON. THE LIGHT CURVE IS A SCAN ON APRIL 15, 1982, WITH STRONG SO<sub>2</sub> BAND STRUCTURE, WHILE THE DARK CURVE IS A SCAN ON MAY 9 SHOWING ENHANCED SCATTERING NEAR 300 nm CAUSED BY AEROSOLS.



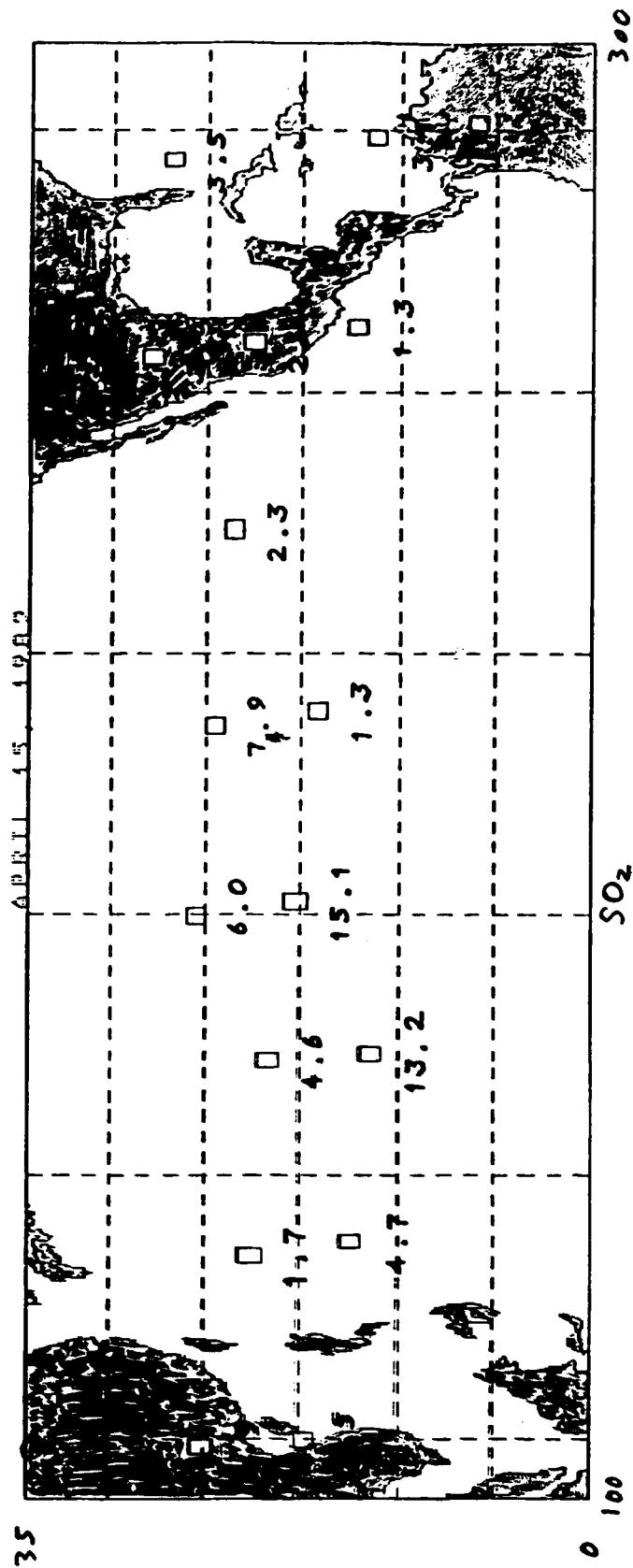


Figure 2. SO<sub>2</sub> AMOUNTS (m-atm-cm) DETERMINED FROM SBUV SPECTRAL SCAN MEASUREMENTS.

COMPARISON OF GROUND BASED AND TOMS MEASUREMENTS OF SO<sub>2</sub>  
FROM VOLCANIC EMISSIONSJames B. Kerr and Wayne J. Evans  
Atmospheric Environment Service

The Brewer Ozone Spectrophotometer is being used in the World Ozone Network to monitor ozone and SO<sub>2</sub>. SO<sub>2</sub> from both natural as well as anthropogenic sources are measured. It has been demonstrated that SO<sub>2</sub> interferes with total ozone values as measured by the Dobson Spectrophotometer and TOMS. A small amount of manmade SO<sub>2</sub> is difficult to detect and quantify by TOMS because it is located near the surface. However, larger amounts of SO<sub>2</sub> injected into the stratosphere from volcanic emissions are detected by TOMS.

There have been some instances when the Brewer instrument was measuring SO<sub>2</sub> from the ground at the same time TOMS was measuring it from space. Results of these comparative measurements are presented.

Introduction

The Brewer Ozone Spectrophotometer and TOMS measure column amounts of ozone and SO<sub>2</sub> by ultraviolet spectroscopy. The Brewer measures both natural and anthropogenically produced SO<sub>2</sub> to a precision of about 1 matmcm and TOMS measures stratospheric SO<sub>2</sub> which usually results from volcanic emissions.

There have been three instances when TOMS detected SO<sub>2</sub> from space on the same day that the Brewer was measuring it from below. These three occasions were after SO<sub>2</sub> was injected into the stratosphere as a result of volcanic emissions. The three eruptions were Mount St. Helen's on May 18, 1980, El Chichon on March 28 - April 3, 1982 and Krafla, Iceland on September 5, 1984. Results of the SO<sub>2</sub> measured in these three volcanic clouds are presented here.

Method

Both ozone and SO<sub>2</sub> have strong absorption bands at wavelengths in the ultraviolet. The absorption spectra for these gases between 300 and 325 nm at a resolution of .5 nm is shown in Figure 1. The A and B short wavelengths for TOMS as well as the five operational wavelengths for the Brewer are indicated.

The method to measure SO<sub>2</sub> and ozone using the direct sun absorption technique with the Brewer Spectrophotometer has been described by Kerr et al. (1980). In this method, the absorption spectra of each gas have been carefully considered prior to selecting the five operational wavelengths. The measured solar

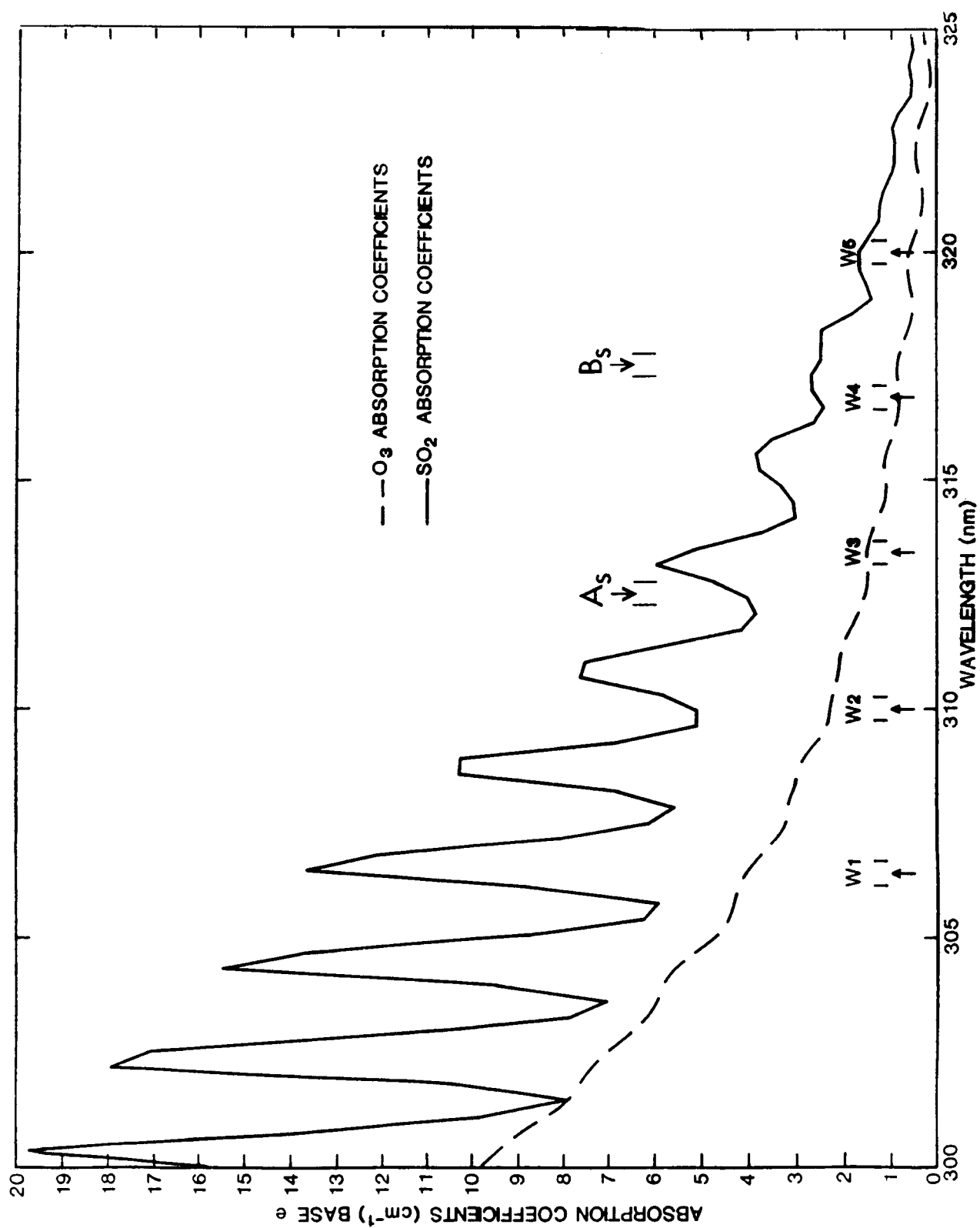


Figure 1.

light intensities at the five wavelengths are used in two algorithms: one is insensitive to absorption by  $\text{SO}_2$  and the other is insensitive to ozone. Kerr et al. (1984) have demonstrated that total ozone as measured by the Brewer is indeed unaffected by the presence of  $\text{SO}_2$  during pollution events at Toronto.

It is evident from Figure 1 that the absorption by  $\text{SO}_2$  at the TOMS A and B short wavelengths is about 2.5 times that of ozone. Therefore, the presence of 1 matmcm of atmospheric  $\text{SO}_2$  causes an apparent increase of 2.5 matmcm ozone for both the A and B measurement. Because ozone and  $\text{SO}_2$  affect the A and B pairs in a similar manner, it is difficult to discriminate between the two gases using the standard ozone inversion algorithms. Following the technique which is used to measure  $\text{SO}_2$  by the Brewer, an algorithm has been developed for discriminating between  $\text{SO}_2$  and ozone has been successfully used to extract stratospheric  $\text{SO}_2$  amounts from the TOMS irradiance data.

## Results

There have been two occasions when significantly large  $\text{SO}_2$  amounts from volcanic emissions were measured by the Brewer from the ground on the same days as TOMS measurements were made from space. Figure 2 shows the TOMS  $\text{SO}_2$  measurements for May 19-20, 1980. Here the  $\text{SO}_2$  which was emitted by the May 18 eruption of Mount St. Helen's is clearly evident.  $\text{SO}_2$  values as large as 100 matmcm were observed on May 20 with typical values of about 60 to 70 matmcm. The leading edge of the cloud was located about 300 km southwest of Toronto (indicated by x) at about 17:00 GMT when the TOMS map was made. The ground based Brewer  $\text{SO}_2$  measurements for May 20-23, 1980 are shown in Figure 3. At about 19:00 GMT on May 20 the  $\text{SO}_2$  readings began increasing and peaked about 70 matmcm at 23:00 GMT. The following day  $\text{SO}_2$  values remained between 30 and 40 matmcm before returning to near normal values near the end of the day. In general, the results of the TOMS and Brewer  $\text{SO}_2$  measurements are in good agreement with regard to both the measured time of arrival of the cloud in the Toronto area as well as the measured values of  $\text{SO}_2$  within the cloud.

The second occasion when both the Brewer and TOMS measured significant values of  $\text{SO}_2$  on the same day was on September 7, 1984 over Norrkoeping, Sweden. This was two days after an eruption of the Krafla volcano in Iceland. Figure 4 shows the drift of the  $\text{SO}_2$  cloud from September 5 to 7 as measured by TOMS. This map suggests that the cloud passed over Norrkoeping (indicated by N) sometime between September 6 and 7.  $\text{SO}_2$  values within the cloud are typically between 30 and 40 matmcm.

The  $\text{SO}_2$  values as measured by the Brewer for September 7 are shown in Figure 5. Observing conditions on this day were very good with a clear sky all day. For comparison  $\text{SO}_2$  on September 6 was typically .4 matmcm and on September 8 it was about 1.0

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# MOUNT ST. HELENS MAY 1980

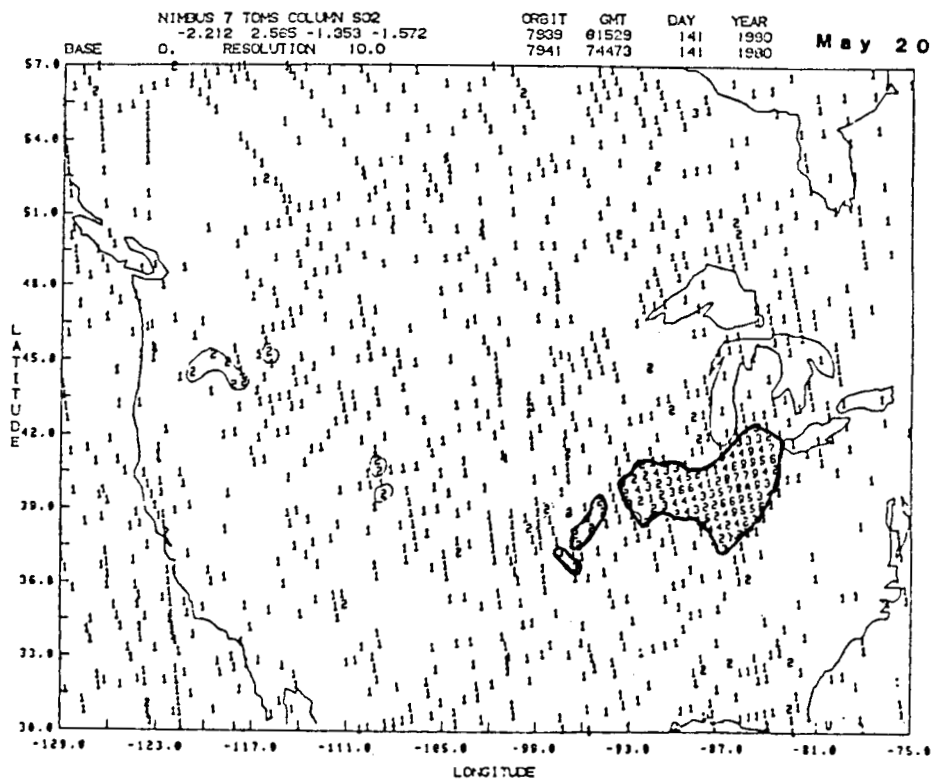
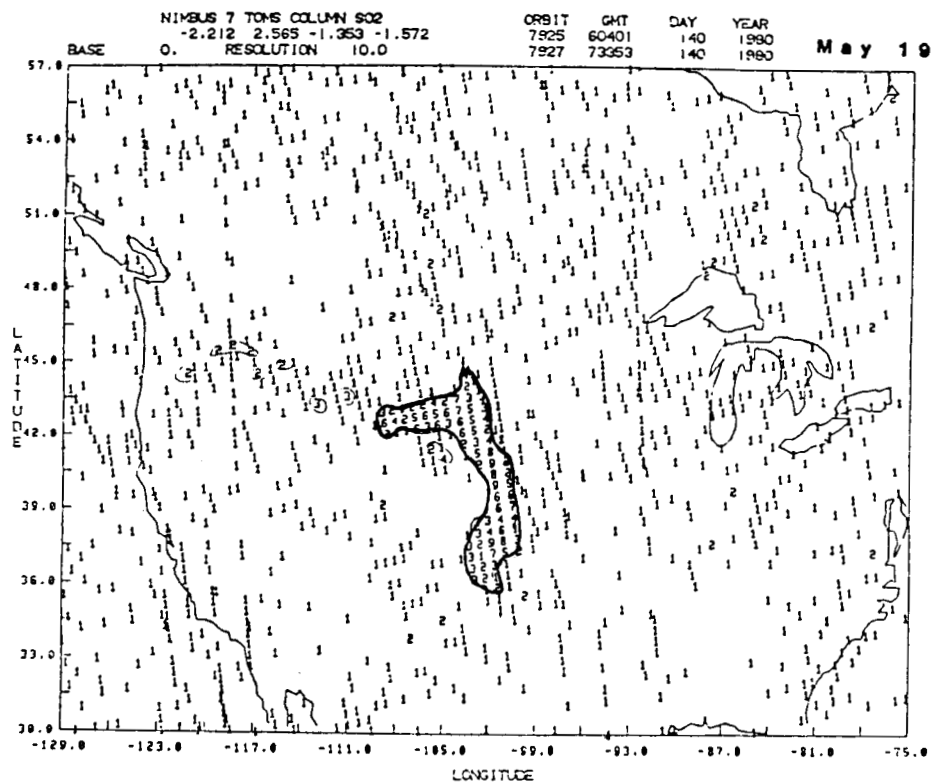


Figure 2.

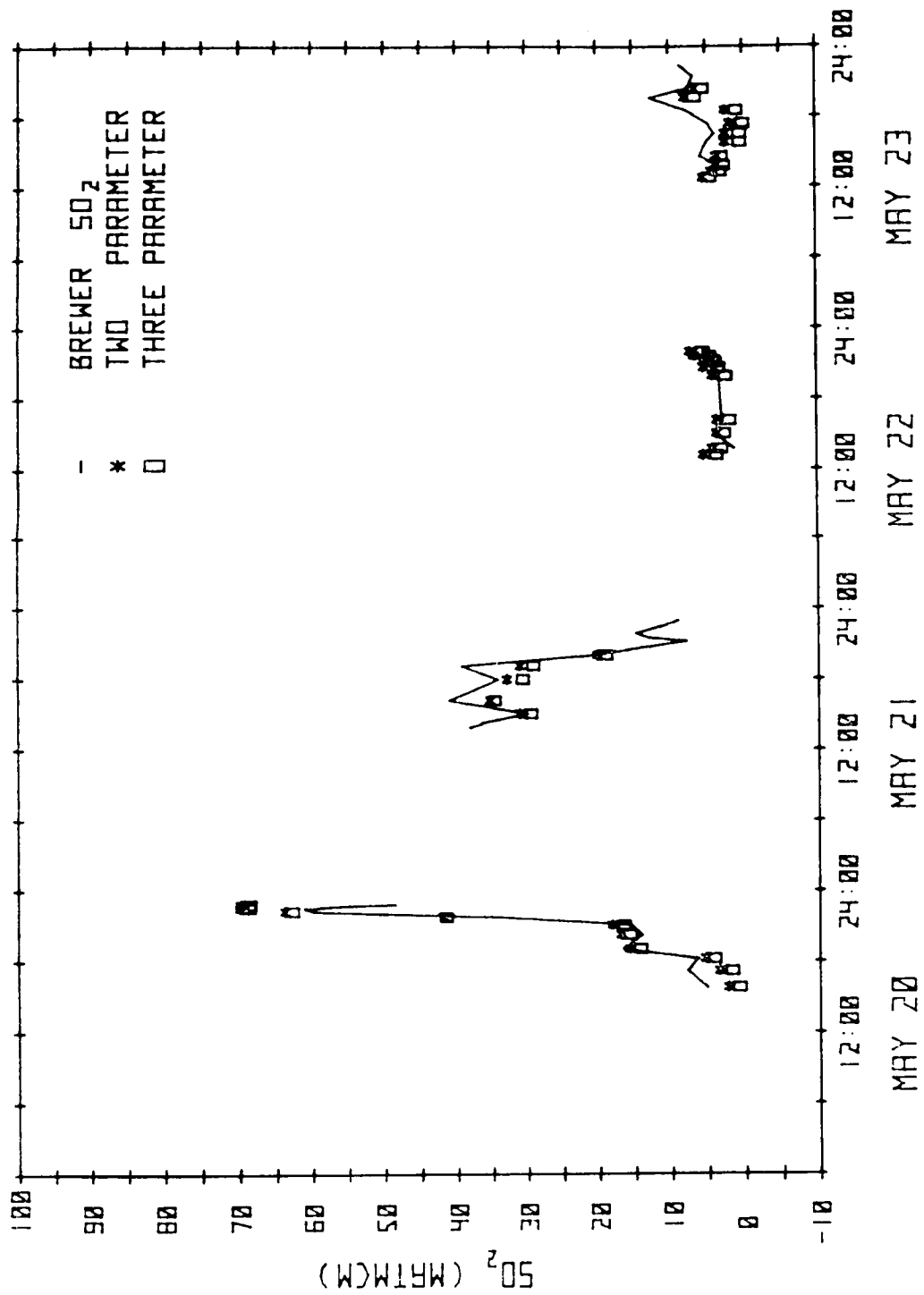


Figure 3.

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Drift of the 5 Sept 1984 Krafla Eruption Cloud

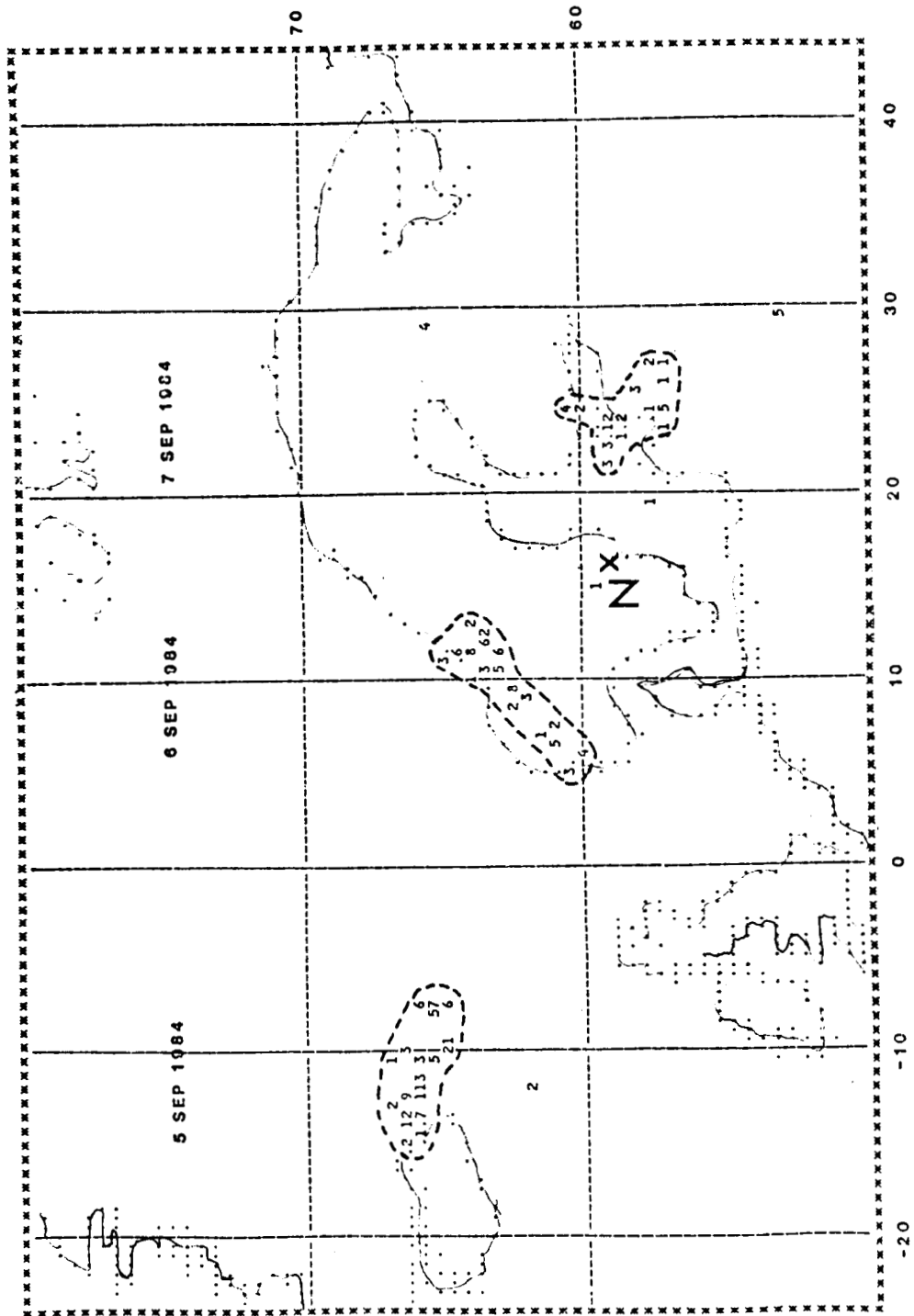


Figure 4.

# SO2 MEASUREMENTS FOR SEPT 7, 1984

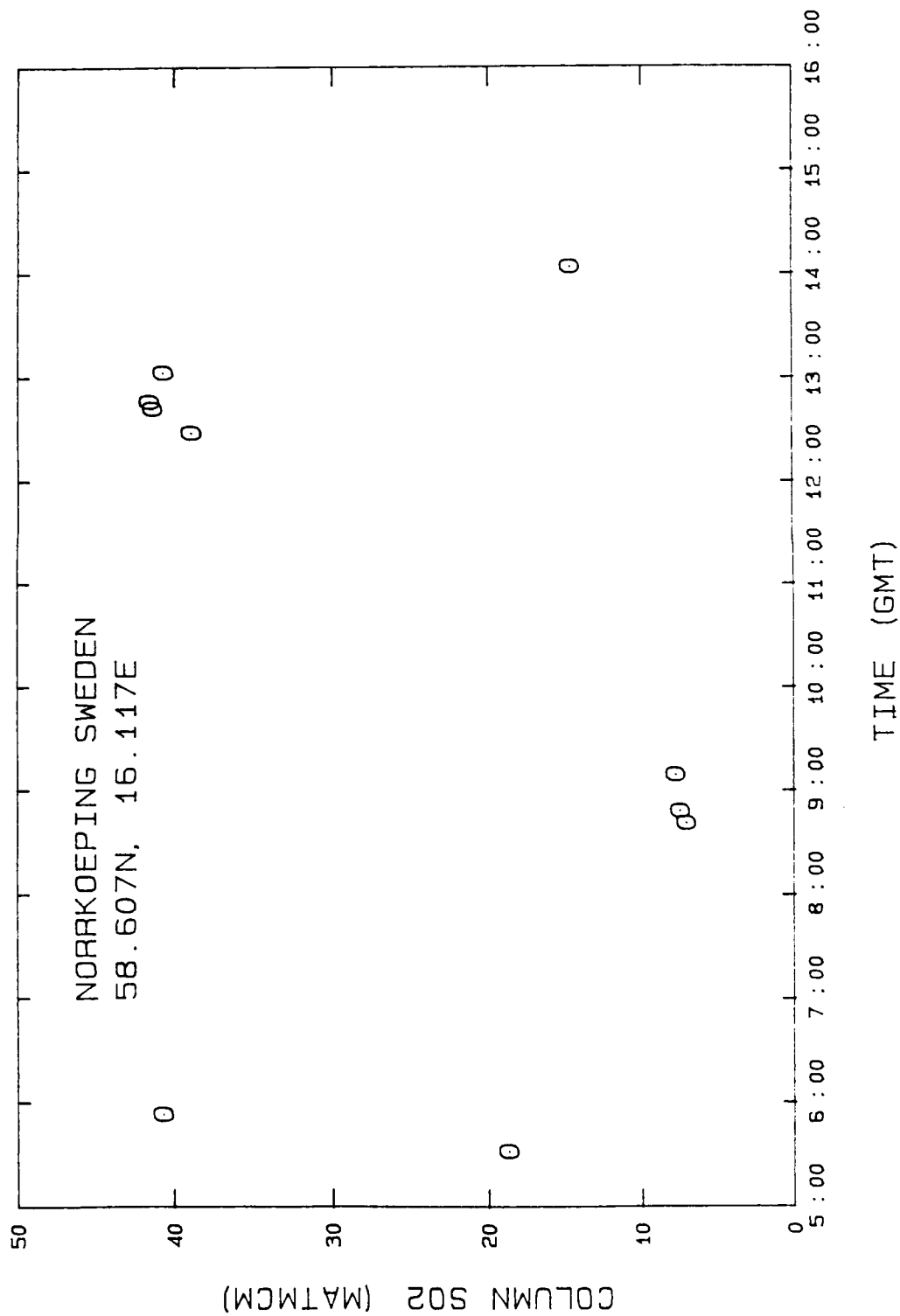


Figure 5.



matmcm. The values in excess on 40 matmcm on September 7 are attributable to the Krafla eruption. The ground based measurements suggest that there are at least two times during the day that the SO<sub>2</sub> column exceeded 40 matmcm: once in the early morning and later in the mid afternoon. When the ground based record is compared with the TOMS measurements, the early morning large values are consistent with the passage of the cloud as measured by TOMS. However, there is no evidence of the second (mid afternoon) cloud on the TOMS record. Air mass trajectory studies suggest that the SO<sub>2</sub> in the later cloud is at pressures between 500 and 700 mb in the troposphere. It is quite likely that the early morning peak is the stratospheric SO<sub>2</sub> which arrived over Norrköping a few hours ahead of the tropospheric SO<sub>2</sub>. Also, it appears that the lower level SO<sub>2</sub> was "hiding" and was not detected by TOMS.

Following the eruption of El Chichon, measurements were made of SO<sub>2</sub> in the remnants of the volcanic cloud. Measurements were made five weeks after the initial eruption when the SO<sub>2</sub> had dispersed significantly. On this occasion, the Brewer made measurements from a NASA CV-990 aircraft which flew under the volcanic debris between 20° and 50° N latitude at a longitude of about 125° W. Figure 6 shows the TOMS measurements for May 6, 1982 with the flight path of the Brewer indicated. There is evidence of slight traces of SO<sub>2</sub>, however, for the most part, the measurements are within the noise of TOMS measurements. Figure 7 shows the underpass measurements made from an altitude of 35,000 ft. There was an abrupt increase from background values of SO<sub>2</sub> to about 5 matmcm at 35° N. The value of matmcm SO<sub>2</sub> is quite likely to be below the detection limit of TOMS.

The TOMS figures were provided by Arlin J. Krueger, GSFC.

## References

J.B. Kerr, C.T. McElroy and R.A. Olafson, Measurements of ozone with the Brewer ozone spectrophotometer, Proceedings of the International Ozone Symposium, Boulder, CO, pp 74-79, 1980.

J.B. Kerr, C.T. McElroy, D.I. Wardle, R.A. Olafson and W.J. Evans, The automated Brewer ozone spectrophotometer, Proceedings of the Quadrennial Ozone Symposium, pp 396-401, Halkidiki, Greece, 1984.

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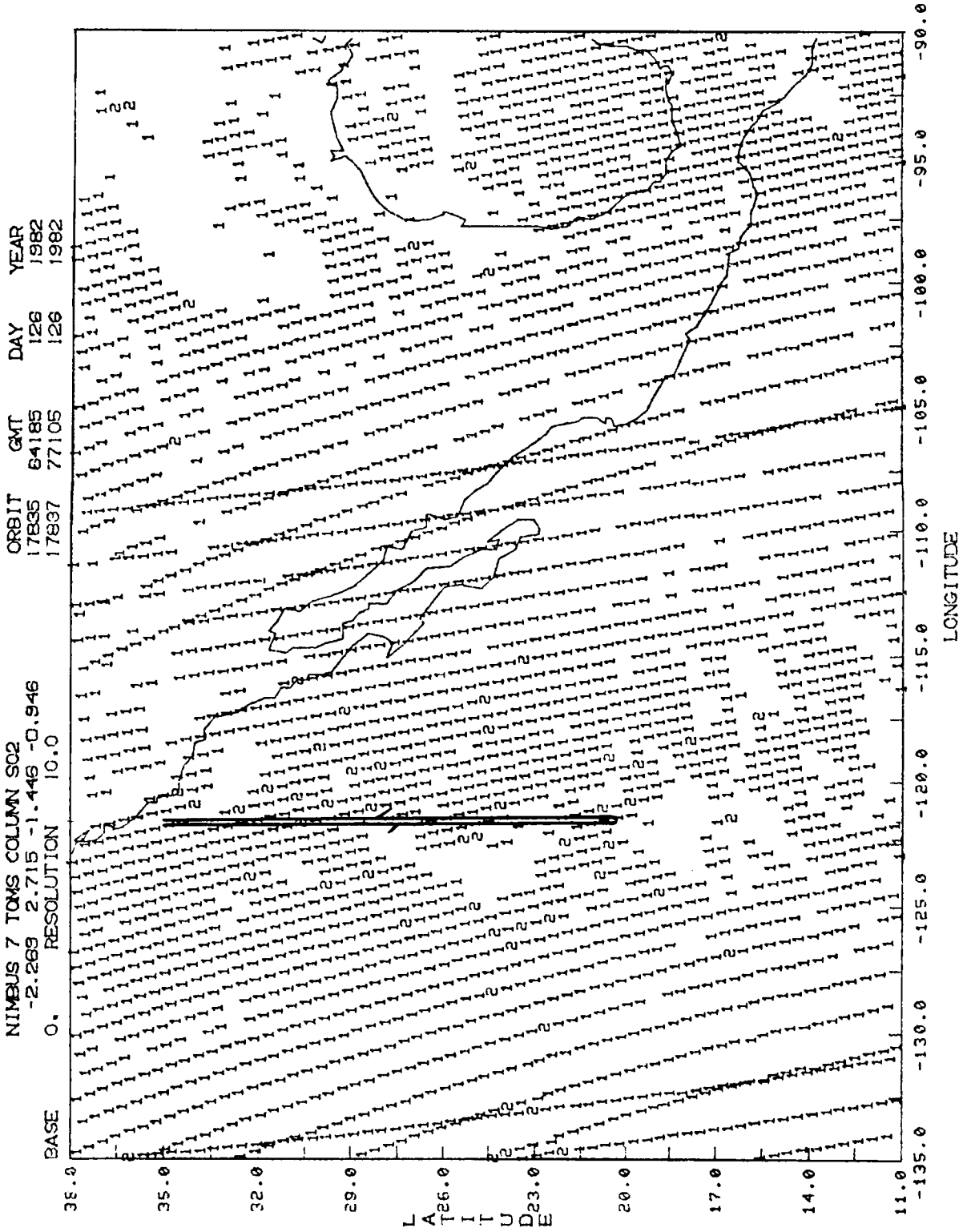


Figure 6.

# **SO<sub>2</sub> MEASUREMENTS FROM NASA CV990 OVERBURDEN OF SO<sub>2</sub> ABOVE AIRCRAFT**

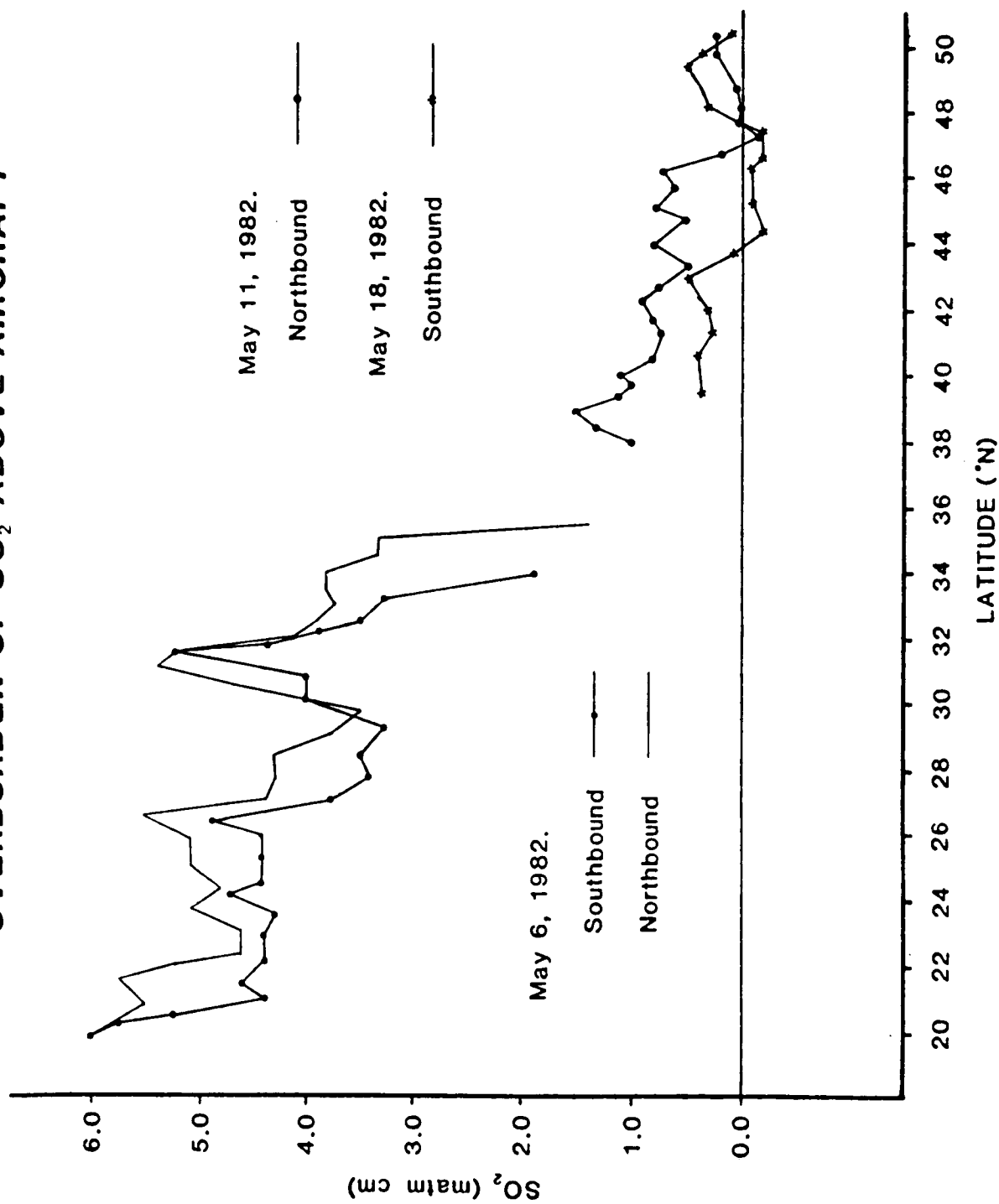


Figure 7.

## TOMS AND THE NOAA/FAA VOLCANO SUPPORT PLAN

Michael Matson  
NOAA/NESDIS

Volcanic eruptions pose several hazards to aircraft encountering the resultant ash cloud. These include windshield pitting, abrasion of exposed parts, erosion of compressor blades, and oil system contamination. During two of the 1982 eruptions of Galunggung volcano in Indonesia, two Boeing 747's which inadvertently flew through the ash cloud suffered multiple engine failures. Because many air routes traverse volcanic areas (e.g., Alaska, Japan, Indonesia), information on volcanic eruptions and ash clouds is important to aviation authorities so aircraft can be rerouted out of the area. Nocturnal eruptions are especially dangerous to aircraft. Visual sighting is difficult and onboard radar is not designed to detect the small ash cloud particulates.

At the request of the Federal Aviation Administration (FAA), the National Oceanic and Atmospheric Administration (NOAA) has prepared a plan for supporting the FAA during volcanic eruptions. The plan utilizes NOAA satellites data and trajectory analysis. Because current operational satellite sensors cannot unambiguously distinguish volcanic eruptions from meteorological clouds, the plan is designed to react to known eruptions rather than detect eruptions. However, the TOMS instrument has been used to unambiguously detect sulfur dioxide clouds from volcanic eruptions regardless of cloudiness. If TOMS was flown on an operational NOAA satellite, NOAA would have an automated volcanic eruption detection system which could more effectively support the FAA.

## USE OF SATELLITE DATA IN VOLCANO MONITORING

Lindsay McClelland  
Smithsonian Institution

The Smithsonian Institution's Scientific Event Alert Network (SEAN) gathers information about volcanic activity throughout the world. Information is quickly disseminated to scientists and government officials so that research and hazard mitigation can begin promptly, then distributed to the world scientific community via the monthly SEAN Bulletin, and excerpts of the Bulletin in the American Geophysical Union's Eos, the American Geological Institute's Geotimes, and the Bulletin of Volcanology. We encourage new initiatives in volcano monitoring that will allow us to more effectively serve the world's volcanological community.

Volcanic activity has an immediate impact on people living nearby and on aircraft flying overhead. It is crucial that eruptions be spotted quickly to allow timely evacuation of people from danger areas, rerouting of aircraft, and detailed scientific monitoring of the activity. However, many volcanoes are located in remote areas with limited communications, and it often takes many days for news of an eruption to reach the scientists and officials who must respond to it.

Satellites have the potential to provide nearly immediate detection of moderate to large eruptions anywhere in the world, and to supply valuable data about eruptions as they progress. To realize this potential, deployment and data utilization need to be improved.

NASA's TOMS instrument can detect anomalous atmospheric concentrations of  $\text{SO}_2$ , usually produced by volcanic eruptions. A tantalizing example of the potential of TOMS was provided during the April 1984 Mauna Loa eruption, when inspection of the TOMS data not only showed an extensive  $\text{SO}_2$  plume originating from Hawaii, but also detected another zone of high  $\text{SO}_2$  concentration over the Galapagos Islands (SEAN Bulletin v. 9, no. 3). This proved to be a previously unreported eruption of Fernandina caldera, and the prompt notification provided by TOMS was a key factor in its timely study.  $\text{SO}_2$  concentration values generated by TOMS data help volcanologists to answer important questions about gas production in moderate to large eruptions, and have shown that the amount of  $\text{SO}_2$  varies considerably between eruptions of similar size and ash content.  $\text{SO}_2$  is a major parent of the  $\text{H}_2\text{SO}_4$  droplets that comprise the bulk of the persistent volcanic stratospheric aerosols that can effect climate, and the  $\text{SO}_2$  content of the eruption cloud seems to be a better predictor of long-term atmospheric effects than the amount of ash erupted.

Unfortunately, financial and organizational constraints currently prevent daily real-time reduction of TOMS  $\text{SO}_2$  data, so

Pavlof Volcano, Alaska Peninsula, USA (55.42°N, 161.90°W). All times are local (= GMT - 9 hours).

At 1225 on 16 March, the pilot of Air Pacific flight S27 observed a white vapor plume rising to 6 km altitude from the volcano and drifting NW. There had been no eyewitness reports of activity at Pavlof since 15 December 1983 (see SEAN Bulletin, v. 9, no. 1). After an increase on 17-21 December, seismicity decreased to the background level of several tens of events per day and remained at that level as of 2 April.

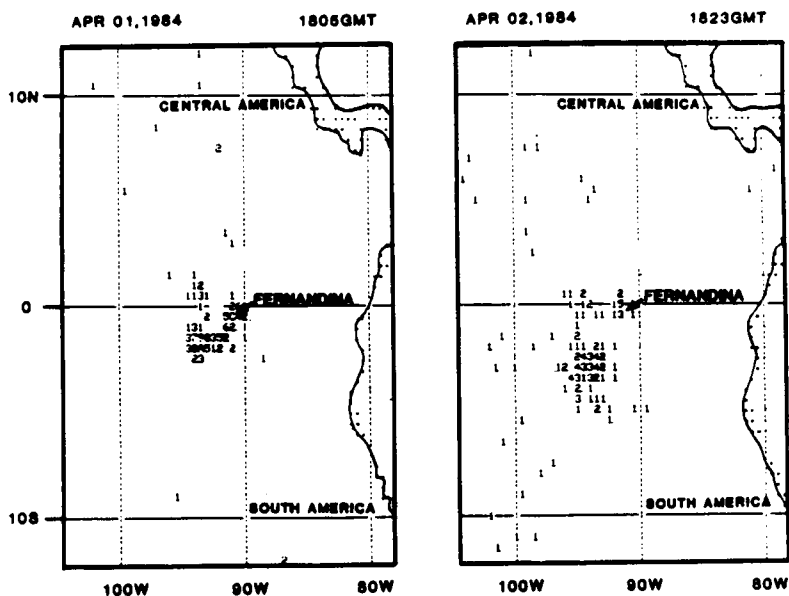
Information Contact: Betsy Yount, U.S. Geological Survey, 4200 University Drive, Anchorage, Alaska 99508 USA; Stephen McNutt, Lamont-Doherty Geological Observatory, Palisades, New York 10964 USA.

Fernandina Caldera, Galápagos Islands (0.37°S, 91.55°W). All times are local (= GMT - 6 hours).

At 0500 on 30 March, Oswaldo Chapí and Fausto Cepeda (of the Galápagos National Park) heard noise from Fernandina Caldera, 22 km SW of their position at Tagus Cove. Glow was visible over the NW end of the caldera and a cloud was seen issuing from the same location after sunrise. The eruption was described as being smaller than the Volcán Wolf eruption of 1982 (see SEAN Bulletin v. 7, no. 8).

On 1 and 2 April, the TOMS instrument in the NIMBUS 7 polar orbiting satellite detected SO<sub>2</sub> produced by the eruption (figure 13). No data were available 30-31 March, and SO<sub>2</sub> had dropped below the detection threshold by 3 April. Strongest values on 1 April were directly over the volcano and a preliminary estimate of total SO<sub>2</sub> was 60,000 metric tons. No eruption cloud was evident on NOAA weather satellite imagery.

Figure 13:  
Preliminary SO<sub>2</sub> data from the TOMS instrument on the NIMBUS 7 satellite, courtesy of Arlin Krueger. All values less than 10 milliatmosphere - cm (100 ppm - meters) have been suppressed. Each number or letter represents the average SO<sub>2</sub> value within an area 50 km across. 1 = 11-15 matm-cm = 101-150 ppm-m, 2 = 16-20 matm-cm = 151-200 ppm-m, etc.; values above 9 is followed by A, B, C, etc.



SEAN Bulletin v. 9, no. 3

March 31, 1984

Reference 1.

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Fernandina Caldera (continued)

On the afternoon of 4 April, the cruise ship Santa Cruz reported a long plume of vapor coming from the caldera, but apparently decreasing in size. They looked for glow over the volcano that night but reported none.

On 11 April Fernandina was climbed from the NW by David Day and L. Peterson, who reported an apparently inactive lava flow reaching from the western side of the caldera (near the site of the major eruption of 1968) to the lake. At 0650 the next morning, Day and Peterson heard a noise "like a large landslide" from their camp near the western caldera rim. Within 30 seconds, they reached the rim in time to see what Day described as a *nuée ardente* that had already moved from the vent area halfway to the lake. They left the rim and observers from Punta Espinoza, 17 km to the NE, described an eruptive cloud rising at 0655 to an estimated height of about 7 km. At 0704, Day and Peterson were overtaken by an ash rain described as "raindrops with ash" and total darkness persisted until 0720. A thickness of 3 mm of tephra accumulated during that period at their rim camp. By 0725 it was clear enough to see into the caldera. Tephra covered the new lava on the caldera floor with the exception of an area a few hundred meters across in which molten lava could be seen. Day and Peterson left the rim at 1030 and no further volcanism had been witnessed at the time of their radio report, at 1500 on 13 April, from Punta Espinoza.

This is the 6th known eruption of Fernandina since the major explosive eruption and massive caldera collapse of 1968. The last eruption was not recognized in the Galápagos, but its products are visible in an aerial photograph taken 26 March 1982. From a 900-m-long circumferential fissure on the S rim of the caldera, flows moved both inward (N) down the caldera wall and over a high topographic bench, and outward (S) where the flow ponded behind another row of circumferential vents. The eruption had not yet taken place when Tom Simkin and others passed this area on 4 December 1980.

Information Contacts: Gunther Reck, Director, Charles Darwin Research Station, Isla Santa Cruz, Galápagos Islands, Ecuador; Lucho Maldonado, Metropolitan Touring, P. O. Box 2542, Avenida Amazonas 239, Quito, Ecuador; David Day, Isla Santa Cruz, Galápagos Islands, Ecuador; Arlin Krueger, Code 963, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771 USA; Michael Matson, NOAA/NESDIS, Room 510, World Weather Bldg., Washington, DC 20233 USA.

Arenal Volcano, western Costa Rica (10.47°N, 84.73°W).

Lava extrusion continued from the vent at 1450 m altitude at the W end of the elliptical summit crater area. The lava flow that had been active in September 1983 (see SEAN Bulletin v. 8, no. 10) stopped advancing in October. During the same month, a new flow (the 43rd since nearly continuous lava production began in 1968) began to emerge, moving NW before halting at 980 m above sea level in November. Another flow (no. 44) started to advance NW in December, remaining active until February, and still another flow moved N between January and March. Extrusion of flow no. 46 started in March and it continued to travel westward late in the month. Rumbles, or sounds similar to those produced by jet aircraft, were often heard in the crater.

Information Contacts: Jorge Barquero and Erick Fernández, Programa de Investigaciones Vulcanológicas y Sismológicas, Universidad Nacional, Heredia, Costa Rica.

SEAN Bulletin v. 9, no. 3

March 31, 1984

Reference 1. (Continued)

this valuable tool remains in only limited use. A further problem is presented by the present and future deployment of TOMS. Currently on the Nimbus 7 polar orbiter, it provides once a day global coverage, but this satellite has already suffered substantial power loss and is expected to fail within the next few years. Launch of another TOMS on a polar orbiter is, therefore, urgently needed. In the long term, however, geostationary satellites would be a better deployment for TOMS. Although polar orbiters provide global coverage, data is returned from a given location only once a day. This limits the timeliness of TOMS data, and also effectively reduces its sensitivity to volcanic  $\text{SO}_2$ . Many explosive eruptions consist of a series of brief pulses of gas and ash release lasting minutes to hours. The resulting eruption plume initially contains high concentrations of  $\text{SO}_2$ , but is quickly dispersed by winds, yielding a larger but less concentrated zone of  $\text{SO}_2$ . In the 12-hour mean interval between explosion and data collection by a polar orbiting instrument, considerable  $\text{SO}_2$  dispersal (and some conversion of  $\text{SO}_2$  to other phases such as  $\text{H}_2\text{SO}_4$ ) will have occurred and concentration within a given  $50 \times 50$  km pixel will have decreased, effectively raising the eruption detection threshold. TOMS deployment on each of the major geostationary weather satellites (the successors of GOES I and II, GMS, and METEOSAT), would provide an improvement in both the timeliness and sensitivity of TOMS data.

Geostationary weather satellite data are available for virtually the entire globe, at half-hour intervals in many areas. Large eruptions such as those of El Chichon in 1982, and Alaid in 1981 were quickly spotted by NOAA scientists and the movement of their eruption clouds tracked over long distances. However, experience has shown that weather satellite data alone are generally of limited value in discovering any but the largest of previously unknown eruptions. Eruption plumes are hidden among the thousands of similar-looking weather clouds that dot the globe and further work is needed to find reliable methods of distinguishing volcanic clouds. Once an eruption is known, visible and infrared data from geostationary and polar orbiting weather satellites have been very effectively used to monitor the timing, dimensions, and altitudes of eruption clouds (see SEAN Bulletin v. 8, nos. 9-10).

TOMS and weather satellite data, therefore, complement each other. TOMS data is most useful for discovering previously unknown eruptions, and yielding a minimum volume of  $\text{SO}_2$  produced by a given eruption. Once an eruption has been reported, weather satellite data can be used to accurately monitor its progress. To be used effectively, these data need to be analyzed jointly and in real time. Toward this end, we hope that full and timely utilization can be made of existing TOMS data, a polar orbiting TOMS can be launched in the near future, and that TOMS-type instruments can be included on future geostationary satellites.



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Una Una Volcano, Sulawesi, Indonesia (0.17°S, 121.61°E). All times are local (= GMT + 8 hours).

A powerful explosive eruption of Una Una began 18 July after at least 10 days of seismicity (see SEAN Bulletins v. 8, nos. 7-8). Since late August, no explosions have been reported by ground observers or seen on satellite imagery. Yoshihiro Sawada searched all July and August images from the Japanese GMS satellite and provided table 1 (next page). Sawada notes that the data are tentative; some of the plumes may have been weather clouds. Times listed in table 1 are the beginnings of image scans, which are completed in about 25 minutes. Images are returned 14 times per day at intervals ranging from 30 minutes to 3 hours. New explosions are indicated by an arrow to the left of the time. Data shown in parentheses are for plumes that are detached from the volcano because explosive activity had (apparently) stopped. A new plume was sometimes ejected before remnants of the previous explosive pulse had dissipated; dimensions of the old plume are then listed in parentheses below data on the new activity. Coldest temperatures at the tops of plumes are shown. Ground observations of the eruption are being compiled by the Volcanological Survey of Indonesia and we hope to include that information in a future issue of the Bulletin.

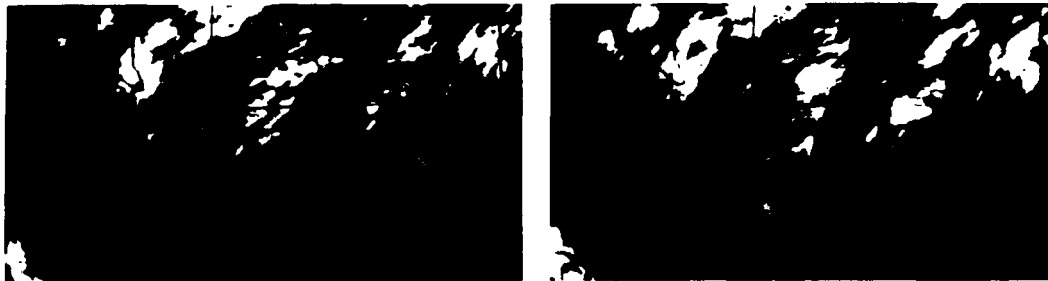
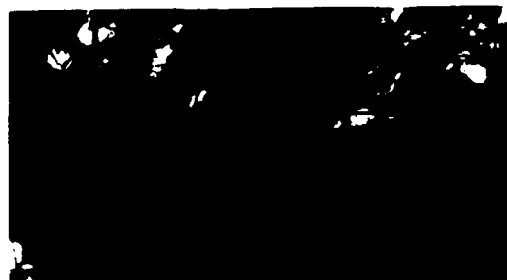


Figure 4: Portions of 3 Japanese GMS geostationary weather satellite images showing the expansion of the cloud produced by the explosions of 23 July, when hot avalanches devastated Una Una island shortly after residents had been evacuated. An arrow points to the eruption plume on each image. Land areas are outlined, from Sumatra and the Malay Peninsula at left to Timor and Halmahera at right. Image scans began at 1631 (above) 1831 (above right) and 1931 (right). Images courtesy of Yoshihiro Sawada.



Information Contact: Yoshihiro Sawada, Seismology and Volcanology Division, Meteorological Research Institute, 1-1 Nagamine, Yatabe, Tsukuba 305 Japan.

Reference 2.

Una Una Volcano, Sulawesi, Indonesia (0.17°S, 121.61°E). All times are local (= GMT + 8 hours).

After at least 10 days of seismicity, a major explosive eruption of Una Una began 18 July. All residents of the island were evacuated before the devastating explosions of 23 July (see SEAN Bulletins v. 8, nos. 7-8). Images and a table of data (beginning 23 July) from the Japanese GMS geostationary weather satellite were shown in last month's Bulletin. A Volcanological Survey of Indonesia team monitored the eruption from near the island. Adjat Sudradjat provided the following table of their observations of explosion times and cloud heights, starting with the 23 July activity.

TABLE 4

DATE	TIME	PLUME HEIGHT (km)	DATE	TIME	PLUME HEIGHT (km)
23 July	1623	10	2-3 Aug.	1905-0200	5
25-6 July	2325-0021	7.5	4 Aug.	0915-1100	6
27 July	0400-0605	7.5	6 Aug.	1520-?	6
	1500-2010	7	7 Aug.	1100-1900	10
28 July	0002-0045	8	11 Aug.	1115-1135	8
	1630-1730	8	12 Aug.	0047-0147	9
30 July	1615-?	6	18 Aug.	1013-1240	12
1 Aug.	1934-2000	7	22 Aug.	1203-?	8
1-2 Aug.	2130-0230	6	24 Aug.	2148-2220	4
2 Aug.	0314-0600	8	25 Aug.	1847-2000	5.5
	0800-0900	8	26 Aug.	1023-1139	10

Maurice Krafft visited Una Una in mid-August. He observed and photographed the 22 August explosion (table 4 and figure 7) and pyroclastic flow deposits from previous explosions (figure 8). The entire island had been devastated except for a narrow strip of undamaged vegetation and villages along the E coast.

Figure 7: Explosion photographed from the south on 22 August by Maurice Krafft. Pyroclastic flows from this explosion continued 1/2 km beyond the SSW coast of the island and 1 km beyond the NNW coast.



Reference 3.

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**SESSION V**

**FUTURE TOMS INSTRUMENT CAPABILITIES**

**Session Rapporteur: Arlin J. Krueger  
NASA/Goddard Space Flight Center**

## Session V - Summary

Session Rapporteur: Arlin J. Krueger  
NASA/Goddard Space Flight Center

This session addressed the question of future measurement requirements and the instrumentation and satellites that are needed. Future flight programs will be derived from the two basic techniques for mapping of total ozone which make use of either ultraviolet absorption or infrared emission. These techniques have been developed independently and have more or less been treated competitively in the past. Each has its own merits but when employed simultaneously the individual advantages and disadvantages can be used fruitfully. However, only the uv technique can be used for all weather ozone sounding and for volcano monitoring.

### MEASUREMENT TECHNIQUE COMPARISONS

The ultraviolet technique is capable of high accuracy if it is designed to measure the albedo of the atmosphere. This technique determines the extinction of sunlight that is reflected by the lower atmosphere, surface or clouds, and therefore, functions uniformly well under all daytime conditions. An example of this technique is the TOMS instrument which uses a spectrometer to measure atmospheric albedo and produces absolute total ozone data. Comparisons with Dobson ground truth stations show agreement within 2%.

The infrared technique is capable of day and night total ozone measurements but appears to be limited in accuracy to about 6% and may be susceptible to latitude dependent systematic errors which drift with time. Valid observations are restricted to cloud-free or broken cloud conditions away from ice caps and polar regions. This precludes accurate measurements in some of the most important situations, such as explosive cyclogenesis.

The uv technique for mapping of total ozone has been implemented in two versions. The first was the TOMS in which the albedo of the earth is obtained by measurements of the earth radiance and the solar irradiance in six 1 nm spectral bands with the same instrument. The second was the DE instrument where the earth radiance only is measured in two 3 nm filter bands and the total ozone is derived by assuming an extraterrestrial calibration constant or by regression against ground truth or TOMS data.

P.K. Bhartia described the selection of optimum uv wavelengths for ozone and sulfur dioxide mapping. With three wavelength

bands, observations of total ozone are possible under all conditions. Additional wavelength bands are needed for measurements of sulfur dioxide and the vertical ozone distribution. At least one band is required for sulfur dioxide while a fifth band is needed for high altitude ozone overburden.

J. Susskind discussed the quality of physical retrieval results from the infrared HIRS ozone soundings. The radiance in the 9.6 micrometer band is determined by temperature, humidity, and clouds as well as by ozone. Thus, several other HIRS channels are required to solve for ozone. The retrievals are, in principle, valid in clear and partial cloud scenes although a number of soundings are averaged together to obtain an adequate signal to noise ratio. In comparison with TOMS the average difference increases with latitude, up to 30% at the highest latitudes. The errors are attributed to limitations of the infrared algorithm since the TOMS data have been validated at all latitudes.

C.P. Cuddapah discussed the complementary aspects of uv and ir data. Only the ir technique operates at night as well as day but appears to be limited to about 6% precision and fails under isothermal stratosphere conditions such as polar night. The uv technique has better accuracy (about 2%) but works only in the daytime.

#### FUTURE REQUIREMENTS

The requirements for data from future TOMS flights cannot be met with a single instrument because of the diversity of uses. For research on stratospheric photochemistry and upper stratospheric dynamics the present polar orbiting instrument provides more than adequate space and time resolution. For the volcanology and air pollution chemistry communities, the polar orbiter provides more than adequate space and time resolution. For the volcanology and air pollution chemistry communities, the polar orbiter provides complete global coverage which is necessary for eruption monitoring and sulfur budget assessment. Thus, a clear need exists for a continuation of the polar orbit data from an instrument similar to TOMS but with wavelengths adjusted for optimum SO<sub>2</sub> sensitivity and for high level ozone overburden. However, for tropospheric dynamics, severe storms, aviation meteorology, and volcanic hazards the temporal resolution of a polar orbiter is far from adequate and the spatial resolution may be inadequate. The needs of these communities can be met only with a geostationary TOMS with temporal resolution of 30 minutes or less.

#### POLAR ORBIT FUTURE

Concern was expressed about the limited remaining lifetime of the Nimbus 7 TOMS instrument, now approaching 8 years age. Mike Comberiate outlined a plan for continuation of the data using the Engineering Model TOMS on the proposed NASA-X satellite. This

mission would use the sidelined NOAA-D spacecraft to fly TOMS, MAPS, MSU and CZCS in a Nimbus-like orbit to be launched at about the Nimbus 7 shutdown time in 1989. The mission, however, is in doubt because of lack of FY87 funding and NOAA's renewed need for the spacecraft in a potential future data gap. Comberiate indicated that strong community support for NASA-X mission was required to establish a higher priority for the mission at NASA Headquarters. A petition was circulated and signed by many of the attendees (see Appendix C).

#### GEOSTATIONARY ORBIT FUTURE

W. Shenk discussed the geostationary observation research needs and indicated the complementary nature of ozone and microwave temperature soundings. Tentative requirements for geostationary observations of total ozone and sulfur dioxide were presented by means of a chart. The factors considered are spatial resolution, temporal resolution, and area of coverage. Other factors of importance in selection of an instrument are flexibility in pointing and in target area designation, the need to observe rapid changes and extreme high or low values. He noted that it is better to err on the side of overdesign due to the research nature of the observations.

G. Keating described a method of modifying either the sounder or the imager for ozone measurements from GOES satellites. This involves adding a beam splitter to direct ultraviolet light to two filter photometers, similar to the approach used on the DE ozone mapper but with parallel channels instead of a filter wheel. The approach has the advantage of the use of an existing telescope and scan mechanism and would undoubtedly cost less than a separate instrument. This instrument would clearly obtain more complete spatial information about total ozone than is available from the infrared ozone channel but would not be able to measure sulfur dioxide because of the bandwidth of the filters. Lacking a diffuser plate for albedo determinations and internal spectral and radiometric calibration methods, the technique will depend on empirical transfer of an ozone calibration from other instruments, such as a TOMS in polar orbit.

O. Maloy described an imaging spectrometer which is being investigated by Perkin Elmer for a geostationary TOMS design. The instrument would image the Earth on a CCD detector after dispersion of the light with a grating. A deployable diffuser plate is used for albedo determination as well as individual CCD element radiometric calibration. The advantages are narrow spectral bandpass, in-flight programmed selection of wavelengths and number of GOES sounder. The design would permit both total ozone and sulfur dioxide soundings as well as vertical ozone profile information. The primary disadvantage deals with the cost of developing a new instrument.

J. Dodge commented that three possible scenarios exist for geostationary observations of ozone and sulfur dioxide. The

first and cheapest option involves use of 9.6 micrometer radiances from an existing channel on the GOES sounder to derive ozone. The second, and more costly option, is the modification of the GOES imager to measure total ozone with the dual channel filter photometer mentioned by G. Keating. This would require changes in an operational instrument and, therefore, needs approval by NOAA, the Metsat Project, and Ford Aerospace for implementation. The third and most flexible but more expensive option is the GSFC/Perkin Elmer imaging spectrometer. It could, however, measure ozone and sulfur dioxide, and meet all the requirements discussed at the meeting.

J. Greaves commented that the accelerated launch schedule for the first three GOES-next satellites precludes most changes. The launch of GOES I is scheduled for October 1988 and J follows in June 1989. Present plans call for K to be launched in October 1989 for in-orbit storage. The remaining two spacecraft, L and M, are nominally planned for 1990 and 1991 launches. Accommodation reviews and Phase A instrument design studies are required in the next year (FY 87) in flight on L and M is anticipated.

## SELECTION OF OPTIMUM WAVELENGTHS FOR OZONE MAPPING FROM SATELLITES

P.K. Bhartia  
SASC Technologies, Inc.

Wavelengths selected for measuring total ozone from the SBUV/TOMS instruments on Nimbus 7 are based on the Nimbus 4 BUUV design. These wavelengths were selected in the late 1960s when the ozone absorption spectrum in the ultraviolet was not known in detail and the sources of uncertainty in measuring total ozone from space were not well understood.

A pair of wavelengths are required to measure total ozone in the ultraviolet. An appropriate set of wavelengths would be those that maximize accuracy and precision, while at the same time, allow retrievals as close to the terminator as possible. The measurement accuracy is improved by selecting the two wavelengths of the pair to be as close as possible. However, high measurement precision requires a large difference in the ozone cross-section at the two wavelengths of the pair. The ability to retrieve ozone near the terminator is improved by selecting wavelengths that have small optical depth in the atmosphere; such wavelengths, however, give inadequate measurement precision elsewhere. Faced with these conflicting requirements, a recommended strategy is to select three wavelengths: one at the peak of ozone absorption cross-section spectrum, another at a nearby minimum and a third wavelength that lies just outside the absorption spectrum. A pair formed using the first two wavelengths are then used under most observing conditions; another pair formed using the last two wavelengths are used near the terminator. There is no evidence that additional wavelengths (up to six in the case of TOMS) provide any benefit for measuring total ozone. Additional wavelengths, however, are necessary if other atmospheric species, such as  $\text{SO}_2$ , need to be measured.



## DETERMINATION OF TOTAL OZONE FROM HIRS2/MSU SOUNDING DATA

Joel Susskind  
NASA/Goddard Space Flight Center

HIRS2/MSU are the two major components of the operational temperature sounding system on the NOAA low earth orbiting satellites. HIRS2 is a 20 channel infrared radiometer, including one channel in the  $9.6 \mu\text{m}$   $\text{O}_3$  band, and MSU is a 4 channel microwave radiometer. The data are analyzed with a multi-spectral physically based retrieval technique which determines surface temperature, atmospheric temperature profile, humidity profile, total  $\text{O}_3$  burden and cloud cover, consistent with the observed radiances. Retrievals are performed globally day and night and in polar winter because sunlight is unnecessary in the infrared region.

Thus far, data from December 1978 to May 1979 have been analyzed and results compared to TOMS products. Day-night differences of retrieved total ozone burden from HIRS2/MSU data averaged over a period of time are generally the  $9.6 \mu\text{m}$  band observations which exhibit a diurnal cycle, such as ground temperature and cloudiness, are well accounted for in the analysis.

The total ozone fields computed from HIRS2/MSU are somewhat noisy compared to TOMS results and show latitude dependent systematic errors which vary slowly in time. We have used systematic errors from previous time periods to correct the HIRS2 soundings. Comparison of fields of HIRS2 and TOMS derived ozone will be shown. Results are encouraging and indicates useful soundings of total  $\text{O}_3$  burden can be done at night and in the polar winter. Ideally, joint infrared, microwave, and ultra-violet systems should be flown on low earth orbiting as well as geostationary satellites to best utilize the complementary nature of the observations.

COMPLEMENTARY INFORMATION BETWEEN UV AND IR FOR REMOTE  
SENSING OF TOTAL OZONEPrabhakara Cuddapah  
NASA/Goddard Space Flight Center

Ultraviolet and infrared satellite techniques have demonstrated their ability to measure total ozone in the atmosphere. However, as the physical principles involved in the two techniques differ considerably, they can convey independent information. The UV method depends on the  $O_3$  absorption and molecular scattering, while the IR method hinges on pressure dependent thermal emission and absorption.

Possible causes for errors in the UV method are clouds in the troposphere, aerosols and UV absorbing gases such as  $SO_2$  in the stratosphere. On the other hand, errors in the IR arise from variations in thermal stratification in the stratosphere, and the tropospheric clouds. When both the IR and UV measurements are available simultaneously with the same field of view, it is possible to minimize some of the errors in measuring the total ozone.

Addition of the IR technique to TOMS type of operation can aid in getting measurements of ozone in the nighttime and during polar night. A radiometer with a channel in the window region around  $11\ \mu m$ , a channel in the  $9-6\ \mu m$   $O_3$  band, and 3 channels in the  $15\ \mu m$   $CO_2$  band should be adequate to retrieve total ozone. Such a radiometer could be designed to do cross track scanning. This combination of UV and IR instruments could be flown on a geostationary or polar orbiting satellite.

OBSERVATION GUIDELINES FOR A TOTAL OZONE MAPPING SPECTROMETER  
(TOMS) IN GEOSYNCHRONOUS ORBIT

William E. Shenk  
NASA/Goddard Space Flight Center

The successful utilization of TOMS measurements in low earth orbit for the analysis of rapidly changing events has led to the consideration of a TOMS in geosynchronous orbit. This orbit should allow the proper selection of temporal and spatial resolutions that are specifically designed for these events plus the flexibility of selecting different sized areas and pointing the sensor to focus on the most interesting events. Separate temporal and spatial resolutions guidelines plus recommended areal coverage have been developed for tropical cyclones, jet streams, the interaction between strong convection and the environment, and the surveillance of volcanoes. It is also suggested that the most effective use of TOMS would be simultaneous flights with microwave and high spectral resolution infrared temperature profiles.

**Table 1. GEOSTATIONARY OBSERVING GUIDELINES — TOMS**

- SIMULTANEOUS FLIGHT WITH OTHER SENSORS FOR PROFILING
  - MICROWAVE
  - IR INTERFEROMETER
- FLEXIBLE POINTING AND AREA SIZE SELECTION
- RAPID (AND SOMETIMES SMALL) TEMPORAL CHANGES VERY IMPORTANT
- GENERAL PHILOSOPHY FOR RESEARCH — BETTER TO OVERDESIGN THAN UNDERDESIGN — DESIGN FOR EXTREMES
- MESOSCALE AND REGIONAL SCALE — HIGH SPATIAL AND TEMPORAL RESOLUTION —

<u>PHENOMENON/FEATURE</u>	<u>TEMP. RES. (MIN.)</u>	<u>SPATIAL RES. (KM-AT NADIR)</u>	<u>COVERAGE (KM-AT NADIR)</u>
HURRICANE			
• EYE AND IMMED. SURROUNDINGS (~3° OF CENTER)	5-10	5-10	500 × 500
• REST OF CYCLONE AND ENVIRONS	30	10-30	3000 × 3000
CONVECTION — ENVIRONMENT INTERACTIONS	5-10	≤10	1000 × 1000
JET STREAMS	10-30	10	1000 × 2000
VOLCANOES			
• INITIAL PHASE (FIRST 12 HRS.)	5-10	5-10	500 × 500
• LATER	30	10-30	3000 × 3000
● FULL DISK COVERAGE			
• ≤60 MIN FREQUENCY			
• 10-30 KM SPATIAL RESOLUTION			

## A GEOSTATIONARY IMAGING SPECTROMETER TOMS INSTRUMENT

Arlin J. Krueger, NASA/GSFC, Greenbelt, MD  
 \*J. Owen Maloy, Mountain Instruments Corp., Irvine, CA  
 H. B. Roeder, Perkin Elmer Corp., Garden Grove, CA

The requirements for a geostationary TOMS include 50 km or better spatial resolution, three to five wavelength bands, time resolution of 30 to 60 minutes, in-orbit measurement of incident and backscattered sunlight, minimum signal-to-noise ratio of 30 at 312.5 nm at the terminator (solar zenith angle = 84 degrees), and 1 nm spectral bandpass to allow discrimination of SO<sub>2</sub> from ozone. These requirements can be met with some difficulty with a mechanically scanned multiwavelength spectrometer similar to the current polar orbiting TOMS design. Alternate designs need to be considered in a pre-Phase A study.

One design with many desirable features is an imaging spectrometer. This type of instrument is now feasible for ozone and sulfur dioxide mapping because of the development of uv sensitive CCD array detectors. A preliminary study makes use of a 0.25 m Czerny-Turner spectrometer with which the earth is imaged on a CCD in dispersed light. The wavelength is determined by a movable grating which can be set arbitrarily by ground control. The signal integration time depends on wavelength but this system allows arbitrary timing by command. Normally a preprogrammed wavelength-integration time sequence would be executed. However, special circumstances, such as a requirement to track a low-lying sulfur dioxide cloud or a need to discriminate high level ozone from total ozone at midlatitudes, could be obtained by adding a particular wavelength to the sequence.

The incident solar irradiance is measured by deploying a diffuser plate in the field of view, similar to the procedure developed with the SBUV/TOMS instruments. This has an added advantage of establishing the calibration of individual pixels in the CCD array. It should be noted that the TOMS technique, in general, makes use of signal ratios to cancel any dependence on absolute calibration. In the proposed design, individual detector elements correspond to scene elements in which the several wavelengths are serially sampled and the earth radiance is compared to the incident sunlight. Thus the problem of uncorrelated drift of multiple detectors is removed.

This suggested design is illustrated in an attached sketch. It appears to meet all of the measurement requirements outlined in previous discussions during the meeting.

\*Speaker

# GEOTOMS - TOTAL OZONE MAPPING SPECTROMETER FOR GEOSTATIONARY SATELLITE

IMAGING CZERNY-TURNER SPECTROMETER (1/4M) WITH FIXED SLITS. IFOW (TOTAL EARTH COVERAGE) SCANNED WITH GRATING FOR SELECTED WAVELENGTHS.

WAVELENGTH RANGE: UV-200 TO 400nm (SELECTABLE); APPROX. 9Kg; 4 WATTS

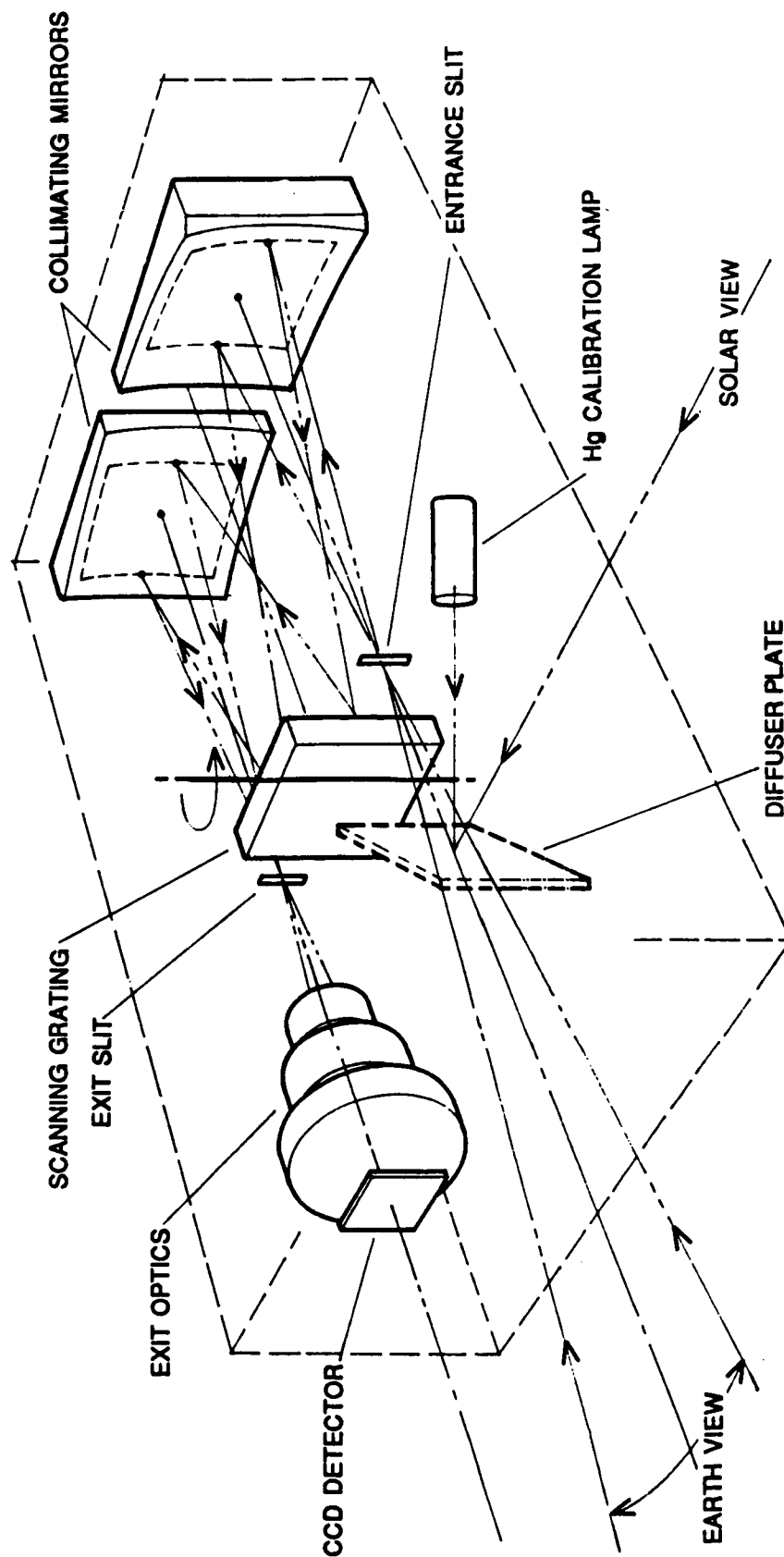


Figure 1.

**APPENDIX A**  
**Communications**

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Department of Geology  
LOUISIANA STATE UNIVERSITY AND AGRICULTURAL AND MECHANICAL COLLEGE  
BATON ROUGE · LOUISIANA · 70803-4101  
504.388-3353 3354

August 29, 1986

Dr. Arlin J. Krueger  
Planetary Atmospheres Branch  
Goddard Space Flight Center  
Greenbelt, MD 20771

Dear Arlin,

I received your notice concerning the upcoming meeting on NIMBUS 7 TOMS. I would be very much interested in participating but my teaching responsibilities will not permit it. I would like to have the opportunity to learn more about the future of TOMS and become directly involved in volcanic gas research using TOMS.

You may be interested to know that two weeks ago in Colombia (10-12 August), we measured 10,000-12,000 tons per day of  $SO_2$  emission from Ruiz volcano. I wonder if that might not be sufficiently large for you to detect. A huge column of gas is continuously emitted and probably has been since June.

I am sorry not to be in attendance at your session. I hope that we can keep in touch about possible future collaboration.

Sincerely,

Stanley N. Williams  
Assistant Professor of Volcanology

SNW:nad

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American Petroleum Institute  
1220 L Street, Northwest  
Washington, D.C. 20005  
202-682-8000



September 15, 1986

Arlin Krueger  
NASA - Code 614  
Goddard Space Flight Center  
Greenbelt, MD 20771

Dear Arlin:

Thank you for inviting me to participate in the September 10-11, 1986 TOMS data workshop. The diversity of uses for satellite ozone mapping data was impressive. Any help that I could provide you in continuing the TOMS system is offered willingly.

At first glance, studies such as those presented by Sechrist would seem to offer the most immediate regulatory benefit. The ability to identify daily areas with stratospheric ozone intrusions would help greatly in appropriately controlling hydrocarbon sources in areas where monitors suggest nonattainment of ozone standards.

Another use of TOMS data might be to supplement extensive "ground truth" surveys of ozone in the lower troposphere. Two such programs that may be of interest are enclosed for your attention. The 1987 ARB study and the ongoing Scenes visibility study may both profit by supportive TOMS analysis. Although our initial attempt to interest CRC was unsuccessful, development of TOMS analyses since then and the larger audience in these programs might lead to a different result. The main problem, as with NOAA, is probably simple ignorance of TOMS usefulness.

A final thought on a potential use of TOMS sulfur dioxide mapping as a tracer for volcanic emissions. Although interesting per se, sulfur dioxide also might be used to estimate emissions of other gases. For instance, the recent NAS report on global warming does not even mention volcanos as a significant source of carbon dioxide. Since volcanic estimates are often based on measurements of SO<sub>2</sub>/CO<sub>2</sub> ratios during eruption where this ratio is high, I suspect volcanic carbon dioxide release is underestimated. During post-eruptive ventings the SO<sub>2</sub>/CO<sub>2</sub> ratio may be very low, e.g. 1/1000. Since most SO<sub>2</sub> release occurs

during non-eruptive phases, the estimated magnitude of volcanic CO2 emission may be low. Should you be able to reduce the TOMS field of view or increase the limit of detection sufficiently to assess the venting phase of volcanic SO2 emissions, a more reliable estimate of total emissions of many other volcanic gases may result.

Sincerely,



Will M. Ollison  
(202) 682-8262

WMO/syc  
Enclosure  
cc: Jack Fishman

**APPENDIX B**  
**TOMS Requirements Summary**

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TOMS Requirements Summary

Amplitude	Lifetime	Dimension/Resolution in km	Ozone Resolution/ Accuracy	Delivery Time	Special Requirements
<b>I. Stratosphere</b>					
Existing specifications satisfactory					
Global Ozone			2%/10 DU drift < 0.5%/yr.	1 week	new channel for column ozone above 10-20 mb, air temperature
Trop.-Strat Exchange	100 DU	1/2 to 1 hr	1000/10-30	1 week	winds, temperature, moisture
<b>II. Troposphere</b>					
Synoptic patterns	300 DU	< 6 hr	2%/10 DU	real time	
Jet stream location	100 DU	3 hr	2%/10 DU	" "	
Turbulence detection	15 DU	1 hr	1%/10 DU	" "	
Tropopause height	300 DU	3 hr	2%/ 5 DU	" "	
Cabin ozone	300 DU	1 hr	2%/25 DU	" "	
Jet stream folds	100 DU	1/2-1 hr	2%/10 DU	" "	air temp., moisture, vertical O <sub>3</sub> distr.; air temp., water vapor
Tropical Cyclones					
- center	60 DU	5-30 min	1%/10 DU	" "	
- environment	80 DU	30 min	1%/10 DU	" "	
Tropospheric ozone					
- biomass burning	10-40 DU	6-12 hr	1-2%	1 day	MAPS carbon monoxide, AVHRR thermal hot spots
- air pollution	10-40 DU	2-10 hr	1-2%	1-6 hr	limited to quiescent stratosphere conditions
Biosphere					
- backscattered radiance			1%/2%	6 months	cloud cover, g 305-380 nm
<b>III. Volcanic SO<sub>2</sub></b>					
explosive eruptions					
- initial phase	200 matm cm	1-12 hr	10 matm cm	real time	winds for plume altitude
- later phases	1-10 matm cm	2-30 days	3 matm cm	1 day	" "
venting	1-3 matm cm	week	0.5 matm cm	6 months	integrate over time

**APPENDIX C**  
**NASA-X Petition**

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National Aeronautics and  
Space Administration



**Goddard Space Flight Center**  
Greenbelt, Maryland  
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Reply to Attn of

614

September 18, 1986

TO: NASA Headquarters  
Attention: Office of Space Science and Applications  
Dr. Shelby Tilford/EE

FROM: Space and Earth Sciences Directorate  
Laboratory for Atmospheres

SUBJECT: TOMS Review Recommendation

At the recent review of scientific and operational requirements for TOMS data it became clear that these data are used in many disciplines, ranging from stratospheric physics and chemistry (e.g., antarctic ozone hole studies), to meteorology (severe storms and upper air analysis improvement), to volcanology and tropospheric air pollution. In addition, it was shown that aviation safety and efficiency would be aided by future operational TOMS instruments.

A deep concern was expressed at the possible interruption of continuity in the TOMS data between the aging Nimbus instrument and the future Polar Platform instruments. As an example, comparison of co-located TOMS ozone data with Dobson station records has resulted in detection of calibration errors and operation mistakes at individual Dobson stations. Even the most trusted stations have been improved by these comparisons. The Dobson network is, of course, a critical component in our system for detection of ozone trends.

The proposed NASA-X satellite offers the best possibility for filling this data gap in addition to its political value in OSSA vitality. Many attendees of the TOMS Review signed the enclosed endorsement of the NASA-X mission as their way of communicating the urgent need for continued global TOMS data. We hope that this will help in getting the NASA-X mission approved.

Concurred

Arlin J. Krueger  
Planetary Atmospheres Branch

Enclosure

Marvin A. Geller, Chief  
Laboratory for Atmospheres

9/18/86

Date

James H. Trainor, Acting Director of  
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Distribution:

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J. Dodge/EET  
D. Butler/EEU  
R. Watson/EEU  
W. Planet/NOAA  
N. Kru11/FAA

Sept 11, 1986

TO: EEU/Dr. R. Watson  
FROM: Nimbus-7 TOMS Workshop Participants  
SUBJECT: Strong Endorsement for NASA-X TOMS Mission

At this workshop (September 10-11, 1986), we were briefed on the proposed NASA-X Earth Science mission (see enclosure). This mission is a unique opportunity to continue critical observations. It appears that there is a possibility to proceed with NASA-X without major impacts to the ongoing Earth Sciences programs and other approved flight projects. With this assumption, we strongly urge that NASA-X be given highest priority among the Earth and Space Science "Vitality" candidates.

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Sept 11, 1986

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